PCT/GB03/00151

10/505461#2

Rec'd PCT/PTO 20 AUG 2004

The Patent Office

INVESTOR IN PEOPLE

PRIORITY DOCUMENT

SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

The Patent Office
Concept House
Cardiff Road
Newport
South Wales
NP10 8QQ

REC'D 08 MAY 2003
WIPO PCT

I, the undersigned, being an officer duly authorised in accordance with Section 74(1) and (4) of the Deregulation & Contracting Out Act 1994, to sign and issue certificates on behalf of the Comptroller-General, hereby certify that annexed hereto is a true copy of the documents as originally filed in connection with the patent application identified therein.

In accordance with the Patents (Companies Re-registration) Rules 1982, if a company named in this certificate and any accompanying documents has re-registered under the Companies Act 1980 with the same name as that with which it was registered immediately before re-registration save for the substitution as, or inclusion as, the last part of the name of the words "public limited company" or their equivalents in Welsh, references to the name of the company in this certificate and any accompanying documents shall be treated as references to the name with which it is so re-registered.

In accordance with the rules, the words "public limited company" may be replaced by p.l.c., plc, P.L.C. or PLC.

Re-registration under the Companies Act does not constitute a new legal entity but merely subjects the company to certain additional company law rules.

Signed AMBrewer

Dated 2 April 2003

BEST AVAILABLE COPY

Patents Form 1/77

Patents Act 1977
(Rule 16)

THE PATENT OFFICE
D
20 FEB 2002
LONDON

The Patent Office

21FEB02 E697627-1 D02000
P01/7700 0.00-0204010.3

Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

The Patent Office

Cardiff Road
Newport
South Wales
NP10 8QQ

1.	Your reference	PDG/24337
2.	Patent application number *(The Patent Office will fill in this part)*	**0204010.3**
3.	Full name, address and postcode of the or of each applicant *(underline all surnames)*	Xaar Technology Limited Science Park Cambridge CB4 0XR United Kingdom
	Patents ADP number *(if you know it)*	7301872002
	If the applicant is a corporate body, give the country/state of its incorporation	United Kingdom
4.	Title of the invention	DROPLET DEPOSITION APPARATUS
5.	Name of your agent *(if you have one)*	
	"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	MATHYS & SQUIRE 100 Gray's Inn Road London WC1X 8AL United Kingdom
	Patents ADP number *(if you know it)*	1081001

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*
a) any applicant named in part 3 is not an inventor, or
b) there is an inventor who is not named as an applicant, or
c) any named applicant is a corporate body.
See note (d))

YES

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form	–
Description	15
Claim(s)	9
Abstract	-
Drawing(s)	34 34

10. If you are also filing any of the following, state how many against each item.

Priority documents	
Translations of priority documents	
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	
Request for preliminary examination and search *(Patents Form 9/77)*	
Request for substantive examination *(Patents Form 10/77)*	
Any other documents *(please specify)*	-

11. I/We request the grant of a patent on the basis of this application.

Signature MATHYS & SQUIRE Date 20 February 2002

12. Name and daytime telephone number of person to contact in the United Kingdom

Peter D Garratt - 020 7830 0000

Warning

After an application for a patent has been filed, the Comptroller of the Patent Office will consider whether publication or communication of the invention should be prohibited or restricted under Section 22 of the Patents Act 1977. You will be informed if it is necessary to prohibit or restrict your invention in this way. Furthermore, if you live in the United Kingdom, Section 23 of the Patents Act 1977 stops you from applying for a patent abroad without first getting written permission from the Patent Office unless an application has been filed at least 6 weeks beforehand in the United Kingdom for a patent for the same invention and either no direction prohibiting publication or communication has been given, or any such direction has been revoked.

Notes

a) *If you need help to fill in this form or you have any questions, please contact the Patent Office on 08459 500505.*

b) *Write your answers in capital letters using black ink or you may type them.*

c) *If there is not enough space for all the relevant details on any part of this form, please continue on a separate sheet of paper and write "see continuation sheet" in the relevant part(s). Any continuation sheet should be attached to this form.*

d) *If you have answered 'Yes' Patents Form 7/77 will need to be filed.*

e) *Once you have filled in the form you must remember to sign and date it.*

f) *For details of the fee and ways to pay please contact the Patent Office.*

DROPLET DEPOSITION APPARATUS

The present invention relates to printing apparatus and in particular drop on demand ink jet printing apparatus.

Digital printing and particularly inkjet printing is quickly becoming an important technique in a number of the global printing markets. It is envisaged that pagewide printers, capable of printing over 100 sheets a minute, will soon be commercially available.

Inkjet printers today typically use one of two actuation methods. In the first, a heater is used to boil the ink thereby creating a bubble of sufficient size to eject a corresponding droplet of ink. The inks for bubble jet printers are typically aqueous and thus a large amount of energy is required to vapourise the ink and create a sufficient bubble. This tends to increase the cost of the drive circuits and also reduces the life time of the printhead.

The second actuation method uses a piezoelectric component that deforms upon actuation of an electric field. This deformation causes ejection either by a pressure increase in a chamber or through creation of an acoustic wave in the channel. The choice of ink is significantly wider for piezoelectric printheads as solvent, aqueous, hot melt and oil based inks are acceptable.

It is an object of the present invention to seek to provide an improved droplet deposition apparatus and an improved droplet deposition actuator.

Thus, according to one aspect of the present invention there is provided droplet deposition apparatus comprising elongate channel walls defining an elongate liquid channel, one of said channel walls being resiliently deformable in an actuation direction orthogonal to the channel length; an ejection nozzle connected with the channel at a point intermediate its length; a liquid supply providing for continuous flow of liquid along the channel; acoustic boundaries at respective opposing ends of the channel serving to reflect acoustic waves in the liquid of the channel; and an actuator remote from the channel and the liquid supply, acting in said actuation direction upon said resiliently deformable channel wall to create acoustic waves in the liquid of the channel and thereby cause droplet ejection through said nozzle.

The resiliently deformable channel wall, preferably located in a wall

opposite to that containing the nozzle forms a liquid seal isolating the actuator from liquid in the channel. The deformable wall may be a common sheet between the actuator and a channelled component.

In a preferred embodiment, the resiliently deformable channel wall comprises a substantially rigid element capable of transmitting force from the actuator to liquid in the channel and at least one flexure element, the rigid element extending along the length of the channel.

The flexure elements constrain the movement of the rigid element to the actuation direction and are preferably stiff with respect to the liquid pressure. A parallelogram linkage to the rigid element has been found to be particularly appropriate and where the actuator comprises a push-rod this can act directly and be carried upon the rigid element.

The actuator itself may be any appropriate device, however, in a preferred embodiment of the actuator the push-rod serves as the armature in an electromagnetic actuator arrangement and in a particularly preferred embodiment the armature is displaced through a modulation of a flux.

In this particularly preferred embodiment the armature is displaced along said actuation direction and a flux of substantially constant magnitude is disposed in an air gap abutting the armature in flux lines orthogonal to said actuation direction. The flux modulation serves to distribute the flux in the air gap to generate force on the armature and thus movement.

A primary magnet is provided to establish a flux and a secondary magnet serves to modulate the distribution of said flux. Neither the primary magnet nor the secondary magnet operating alone are capable of imposing a force upon the actuator in the actuation direction..

Desirably, the primary magnet comprises a permanent magnet and the secondary magnet an electromagnet. The primary magnet establishes a flux in an air gap whilst the secondary magnet is positioned substantially within said air gap.

A stator component can be provided that comprises a slot into which the coil is disposed, the slot opening to said air gap. The coil can be coaxial with the actuation direction or a flat multi-turn coil disposed in a plane orthogonal to the actuation direction.

Preferably, said modulation in distribution of a flux comprises the modulation of the distribution of air gap flux density along a line in the actuation direction, advantageously an increase in flux density at a first air gap location and a decrease in flux density at a second air gap location, the first and second air gap locations being spaced in the air gap direction.

Advantageously, said increase in flux density at a first air gap location and a decrease in flux density at a second air gap location, is achieved through constructive and destructive interference, respectively between a switchable magnetic field and a constant magnetic field.

It is preferred that the actuator is formed via a MEMS technique in that it is a laminate manufactured through the repeated formation and selective removal of layers.

In a second aspect of the present invention, there is provided droplet deposition apparatus comprising an elongate liquid channel capable of sustaining acoustic waves travelling in the liquid along the length of the channel, a droplet ejection nozzle positioned for the ejection of a droplet in response to said acoustic waves and an electromagnetic actuator serving on receipt of an electrical drive signal to create an acoustic wave in the channel and thereby effect droplet ejection.

The actuator, preferably remote from the channel, can extend along substantially the length of the channel and operates in an actuation direction orthogonal to the channel length to resiliently deform an elongate channel wall in the actuation direction under the action of said actuator.

As mentioned earlier, the resiliently deformable channel wall should form a liquid seal isolating the actuator from liquid in the channel. Acoustic boundaries at respective opposing ends of the channel serve to reflect acoustic waves in the liquid of the channel and an ejection nozzle is connected with the channel at a point intermediate its length whilst a liquid supply provides for continuous flow of liquid along the channel.

One of the acoustic boundaries may be a wall, comprising a nozzle. In this situation only one liquid supply is provided in the ejection chamber, typically located at the opposite end of the chamber to the nozzle.

In a further aspect of the present invention, there is provided droplet deposition apparatus comprising an elongate liquid channel bounded in part by a resiliently deformable diaphragm; a liquid supply for the channel; an ejection nozzle communicating with the channel; and a push-rod which is separated from the liquid by the diaphragm, the push-rod being displaceable in an actuation direction orthogonal to the length of the channel to deform the diaphragm to displace liquid in the channel and thereby cause droplet ejection through said nozzle, wherein the push-rod is supported by at least one flexural element at two locations spaced one from the other in the actuation direction.

In a further aspect of the present invention, there is provided a method of manufacturing droplet deposition apparatus, comprising the steps of forming a first planar component comprising a plurality of rigid channel walls corresponding with a set of parallel channels and a resiliently deformable channel wall for each channel, said resiliently deformable channel walls lying in a common plane; and forming a second planar component comprising a linear actuator for each channel, said actuators having respective actuation directions which are parallel; the first and second planar components lying in a parallel relationship in the manufactured apparatus, with said actuation direction disposed orthogonal to said common plane and the actuators serving to actuate the respective channels through deformation of the associated resiliently deformable channel walls.

The invention will now be described, by way of example only, with respect to the following drawings in which:

Figure 1, depicts in perspective a view from underneath a channelled component according to one embodiment of the present invention;

Figure 2, depicts in sectional view a printhead according to a second embodiment of the present invention;

Figure 3a), shows in perspective under view printhead according to a further embodiment of the present invention;

Figures 3b) to 3i) depict in respective sectional views steps in the manufacture of the printhead shown in Figure 3a);

Figure 3j), depicts in sectional view the actuation of the printhead shown in Figure 3a);

Figure 4, shows a variable reluctance type magnetic actuator in a printhead according to an embodiment of the present invention;

Figure 5, depicts in a similar view an alternative type variable reluctance type magnetic actuator;

Figure 6, shows a Lorenz force actuator in a printhead according to an embodiment of the present invention;

Figure 7, is a flux modulation actuator in a printhead according to an embodiment of the present invention;

Figure 8a), is a expanded view of the flux modulation actuator of Figure 7 showing field lines;

Figures 8b) to 8d), are views similar to Figure 8a) respective orientations adopted by the actuator in use;

Figure 9, depicts key dimensions in the arrangement of the bias flux actuator

Figure 10, is a graph showing F_x vs x for the bias flux actuator with i=0

Figure 11, is a graph of F_x vs i for the range $-kg < x < +kg$

Figure 12, depicts a flux modulation actuator coupled to an ejection

chamber via a push-rod spacer plate

Figures 13a to 13i, depict steps in the manufacture of the actuator shown in Figure 12; and

Figure 14 depicts an alternative actuator arrangement.

One of the benefits of the present invention is that the printhead itself can be formed from a number of individually manufactured components. The first component comprises the actuator element whilst a second component comprises the channel structure. Other features may be manufactured as separate components or may be formed as part of the components above.

Figure 1 depicts the channelled component in one embodiment of the invention. A sheet of silicon, ceramic or metallic material 1 is etched, machined or electroformed as appropriate to form a plurality channels, separated by walls 2, extending the length of the component. The component comprises a resiliently deformable wall 4 that extends part of the way along the channel. The wall forms the base of the ejection chamber and is deformed by an actuator (not shown), remote from the channel, acting on its reverse side. At either end of the resiliently deformable wall through ports 6 are provided that act to supply ejection fluid to the completed actuator.

A cover component 8 of a Nickel / Iron alloy, such as Nilo42, is attached to the top surface of the channelled component and comprises through ports for alignment with nozzle orifices 12 located in a nozzle plate 10.

The width W_c, Height H_c, and Length L_c of the ejection chamber have dimensions that satisfy the conditions W_c, $H_c << L_c$. L_c being determined from the operating frequency and the speed of sound in the chamber and is typically of the order 2mm. The nozzle is positioned mid-way along the chamber and each end of the chamber opens into the manifold formed by the through ports 6.

In operation, the manifolds can either both supply ink to the chamber or the supply arrangement can be such that ink can continually be circulated through the chamber, one of the manifolds returning the excess and unprinted fluid to a

reservoir.

The open ends of the chamber provide an acoustic boundary that reflect the acoustic waves in the channel. These reflected waves converge at the nozzle and cause droplet ejection. Thus, the manifolds must have a large cross-sectional area with respect to the size of the channel in order to achieve an appropriate boundary.

The resiliently deformable wall 4 comprises a directly or indirectly attached actuator element. The actuator element is positioned on the opposite side of the resiliently deformable wall to that facing the nozzle and is thus located remote from the ejection chamber. The actuator causes the deformable wall to deflect orthogonally with respect to the direction of chamber length to generate the acoustic waves. The initial direction of movement can be either towards or away from the nozzle.

By repeatedly actuating the deformable wall in quick succession it becomes possible to eject a number of droplets in a single ejection train. These droplets can combine either in flight or on the paper to form printed dots of different sizes depending on the number of droplets ejected.

In Figure 2, a more complex silicon floor plate 20 is used to transmit the force of the actuator element 22 to the ejection chamber 24 rather than the simple flat diaphragm 4 of Figure 1. The plate 20 is formed from two etched silicon wafers bonded together by adhesive or other standard silicon wafer bonding methods and performs two functions. In the first instance it needs to support the actuator and provides a restoring force to bring the actuator back to its steady state rest position as well as to prevent bending forces and moments on the plate from being transmitted to the actuator.

In the second instance the floor plate must be sufficiently stiff so that the volumetric compliance due to changes in ink pressure is low otherwise the acoustic velocity in the ink will be adversely affected.

The floor plate can be seen as effectively forming a parallelogram linkage 20.1 and a rigid element 20.2, the actuator acting directly onto the rigid element and the parallelogram linkage comprising flexure elements 20.3.

The usefulness and benefits of such a floor plate will be described in

greater detail with regard to Figure 12.

Whilst, in this example, the floor plate is considered to be a separate plate, it is equally possible to form it as part of the channelled component as will be described with reference to Figure 3.

The channels are at the underside of the component as seen in Figure 3a and are not visible.

Push-rods 30 are formed integrally with the floor 34 of the ejection chamber. A base plate 38 is attached to the component such that it extends over the upstanding walls 32 and isolates the push-rods and the push-rod chamber 36. This base plate is flexible, thus providing a flexible linkage for the end of the push-rod remote from the ejection chamber.

The manufacture of the channelled component of Figure 3a is preferably achieved by a mixture of wet etching and deep reactive ion etching (DRIE). A silicon plate is provided and, as shown in Figure 3b, is etched from one surface using DRIE to form the ejection chambers 24 and walls dividing the ejection chambers 33.

At a predetermined depth etching is halted and an etch stop layer 34 of silicon dioxide and / or silicon nitride is deposited over the surface of the ejection chamber as depicted in Figure 3c. From the opposite side, by DRIE, the pusher rod 30 and dividing walls 31 are formed with the etchant removing silicon to the previously formed SiO_2 and / or SiN layer 34. Because this layer is not removed a thin flexible membrane, as in Figure 3d, remains to separate the ejection chamber from the pusher rod chamber 36.

In Figure 3e, a second silicon plate 33 is bonded to the side of the first plate comprising the pusher rod chamber 36. This second plate has a two layer coating, namely SiO_2 35 overlaid with a coating of SiN 37, with the SiN preferably extending over a greater area of the second plate than the SiO_2. The second silicon plate 33 is a sacrificial layer that is subsequently removed by wet etching to leave a flexible membrane of SiN and SiO_2 as depicted in Figure 3f.

As in Figure 3g, an actuator (depicted schematically through armature 39) can then be formed on the SiN and SiO_2 membrane using MEMS fabrication techniques. (This process is later described in greater detail with respect to

Figures 13a to 13i.) The final steps are to remove the SiN or SiO_2 layer that remains in the ink supply ports 6 and to apply cover and nozzle plates.

Figure 3h is a view along line B-B of Figure 3a before the membranes 34 and 35,37 within the ink supply ports 6 are removed. These are removed, preferably by wet etching, to open up the supply ports and allow ink to flow along the ejection chamber. A cover plate is added in Figure 3i.

Figure 3j shows the cross sectional view across line A-A of Figure 3a. The ink channel 24 is bounded on one side by the resiliently deformable channel wall 34, a nozzle plate 31 forming the wall opposed the resiliently deformable channel wall and two rigid non-deformable walls 33.

The pusher-rod 30 is positioned in a chamber located between the resiliently deformable wall and the resiliently deformable base plate 35,37. An actuator is positioned such that an armature 39 acts on the opposite side of the resiliently deformable base plate to the pusher rod.

As the actuator acts on the pusher-rod, both the resiliently deformable floor plate and the resiliently deformable base plate are deformed. In certain circumstances it is desirable that the stiffness of the two resiliently deformable plates is chosen to be different. However, it is equally sufficient that the two resiliently deformable plates are of the same stiffness.

It has also been depicted that the walls 33 bounding the ejection chambers 24 and the walls 35 bounding the pusher-rod 36 chamber are of equal thickness. However, according to particular resiliency of the deformable walls it is sometimes desirable to alter the thicknesses of the walls 33, 35 such that one is thicker than the other.

The actuator, which may include the resiliently deformable base plate, is preferably attached as a plate structure. A preferred method of construction is described later with respect to Figure 13.

As mentioned earlier, the actuator is formed distinct from the channelled component and therefore a number of different types of actuator are appropriate for use with the above described channelled component. The present invention is in certain embodiments particularly concerned with electromagnetic actuators and with new types of electromagnetic actuators preferably manufactured by a MEMS

technique.

Figure 4 depicts a magnetic actuator operating according to variable reluctance force. The channelled component 42, and nozzle 44 are formed as described with reference to Figures 1 to 3 above.

An armature 46, is formed from an electroformed, soft magnetic material such as Nickel/Iron or a Nickel/Iron/Cobolt Alloy. The armature is designed to provide an element of spring to aid deformation and recoil.

An electroformed stator component 48 of a soft magnetic material is provided with a copper coil 50 encircling the stator core 52. In operation, a DC current is passed through the coil to generate a magnetic field that attracts the armature. The volume of the ink channel is thus increased in order to initiate an acoustic wave. At an appropriate timing, equal to $\frac{1}{2}L_c/c$, (where L_c is the effective channel length and c is the speed of sound in the ink) the current is removed to allow the armature to recoil. The recoil reinforces the reflected acoustic wave in the channel and causes a droplet to be ejected from the nozzle 44.

An alternative form of variable reluctance type actuator is depicted in Figure 5. The spring element 56 is formed as a diaphragm of etched silicon or some other other non-magnetic material. A stator 58 forms a central area through which a portion 64 of the armature 62 extends in order to be in contact with the diaphragm. A coil 60 is provided within the stator adjacent to a portion of the armature 62 having a large surface area.

Upon actuation, the armature is attracted towards the stator and thus deflects the diaphragm into the channel and causes droplet ejection from the nozzle.

Figure 6, depicts an actuator capable of deflecting using a Lorentz force. A channelled component is formed as described earlier and the actuator component is formed as a separate component and attached to it. An etched silicon actuator plate 74 is formed with a number of holes through which a moveable armature structure is posted. A stationary coil 78 is attached to the underside (or in an alternative embodiment to the upper-side) of the etched silicon plate between the plate and the diaphragm 100.

The movable armature structure consists of two metallic extensions 76, 77

joined by a permanent magnet 84. The middle extension is posted through the annulus defined by the coil and is joined to the diaphragm 100. The outer extension extends around the coil and is shorter than the middle extension.

Application of a current to the coil interacts with the permanent magnetic field according to the Lorentz force equation and has the effect of moving the middle extension to deflect the diaphragm. This deflection results in ejection of a droplet from the nozzle.

The preferred magnetic actuator is described with respect to Figure 7. This actuator can be defined as a slotted stator actuator that is deflected by modulating the airgap magnetic bias flux field distribution. The actuator armature 98 moves in the direction of arrow F and pushes against a diaphragm 100 to induce a pressure disturbance, and hence an acoustic wave, in the ink within the ink chamber 102.

The actuator component consists of a permanent magnet 92 that lies between a slotted stator plate 94 and the flux actuator plate 90. The slot of the slotted stator plate contains a multi-turn excitation coil 96. This coil, when excited with a DC current, generates a constant axial force F on the shaped armature 98. Beneficially, the magnitude of the force F is directly proportional to the magnitude of the current i.

Figures 8a to 8d depict the actuating principle of the actuator. Figure 8a shows the path of the field lines from the permanent magnet. As shown in figure 8b, when no current is flowing through the coil the field strengths 120a, 120b are similar at both pole faces of the slotted stator 94. This is achieved by making the armature pole face 'ab' shorter than the stator pole face 'cd'.

When a DC current is passed through the coil the flux lines and field strength are distorted as depicted in Figure 8c. Using the equation:

$$W = \int \tfrac{1}{2}B^2 / \mu \, dV$$

where W is the total energy of the system, B is the flux density in the air gap, μ_0 is the magnetic permeability of free space and V is airgap volume, it can be seen

that, because B is squared, the total energy in the system is greater in Figure 8c than in Figure 8b.

By the principle of least action, the system attempts to revert to the lowest energy state. The armature is therefore moved down in relation to the stator poles in order to minimise the active height Y_1 as depicted in Figure 8d.

By reversing the current, it is possible to deflect the armature in the opposite direction thus pushing the diaphragm and decreasing the volume of the ejection chamber.

The dimensions of the actuator are dimensioned with regard to the air-gap g and the required travel t as shown in Figure 9.

In this arrangement, the travel t of the armature defines the height of the stator pole faces x_5, x_6. Preferably, the distance x_1 is a half of x_5 as this serves to provide an equal linear movement in both of the actuation directions. It is desirable that x_1 remains within the range $g \leq x_1 \leq (x_5 - g)$ as field edge effects begin to apply stress to the coil and reduce actuator efficiency outside this range. A clearly defined shoulder 91 serves to define the air gap spacing g and the air gap volume v. The air gap between the flux actuator and the flux actuator plate 90 is also important, hence the overhang 93. This air gap is also of the order g.

Typical dimensions are:

$$x_5 = x_6$$
$$x_5 = t + 2kg$$
$$y > 2g$$
$$x_3 \geq t/2 + kg$$

where k will typically lie in the range 1 to 3.

It is important that the shape of the armature and the geometry of the air gap are such that the armature has a minimum energy position on excitation of the coil and that this minimum energy position is displaced in the actuation direction from the rest position. This is achieved in the described

arrangement essentially through shoulder 91. A wide variety of other orientations are of course possible.

One advantage that the slotted stator or bias field magnetic actuator has over the Lorentz forms of magnetic actuator is that the force acting on the coils is weak. The coils themselves are formed as multiple coils in multiple layers and the limited size of the actuators makes the coils susceptible to damage. Thus, it is important to reduce the force acting on them.

A second advantage is that the armature mass is minimised compared to the Lorenz force types. Minimising the armature mass results in maximising the operational frequency of the droplet deposition device.

Advantageously, when compared with a variable reluctance actuator, the force developed is substantially linearly dependent on current regardless of the polarity of the current. With variable reluctance type actuators, the force is a function of the air gap and is therefore very sensitive to manufacturing tolerances. This requirement for high tolerance is reduced in the flux modulation actuator.

Looking in greater detail at the armature force, it has been found that the armature force F_x can be plotted as a function of the armature position. The graph for the situation where no current is flowing in the coil is given in Figure 10.

It has been noted that there is a dead band lying approximately in the range $-kg < x < +kg$ where the armature force F_x is close to zero. A field from the permanent magnet is, however, continually present but force is only applied to the armature when a current is applied to the coil. When a non zero coil current i is applied to the excitation coil, the magnetic field in the air gap 'ab' is distorted with the field in the slot remaining relatively weak. This field distortion generates a force on the armature.

In the case where the flux density in the air gap due to the permanent magnet is B, the coil length L and the coil has N turns, the flux linkages with the coil is $2B\Delta xLN$ when the armature moves upwards by a distance Δx in time Δt.

By the conservation of energy and the principle virtual work, the force F acting on the armature is given by

$$F\Delta X = (2B\Delta XLN / \Delta t)i\Delta t$$

So that F = 2BLNi

The force of the actuator plotted as a function of the coil current is given in Figure 11. The linear nature of the force makes this type of actuator easily controllable simply by varying the current through the coils.

Figure 12 depicts the bias flux actuator attached to an ejection chamber through a pre-described push-rod plate. As mentioned earlier it is a requirement that the push-rod plate does not transmit rotational and bending forces from the floor of the ejection chamber to the actuator.

In the bias field actuator, the air gap spacing is important in defining the dimensions of the armature element. It is noted that, in this embodiment, the armature is fixed only at one point, namely to the channelled or push-rod components. Since the opposite end is free to move within the stator any rotational and bending forces will be transmitted to the armature. This will have a bearing on the air gap and thus the flux density within the air gap. The push-rod component serves to prevent this error.

The actuator plate component can be formed through the repeated formation and selective removal of layers. Appropriate techniques include those known as MEMS fabrication techniques.

In Figure 13a, a patterned photo resist 120 is deposited onto the resiliently deformable pusher-rod plate 100 of Figure 12. Subsequently a layer of electroformed nickel alloy 122 is deposited. The nickel alloy will form the first part of the armature and a support for the stator. The photoresist, once removed will form an air gap.

Onto the layer of Figure 13a, a further layer of photoresist and metal alloy is deposited as shown in Figure 13b. These steps may repeated a number of times until the desired structure is achieved.

In Figure 13c, a permanent magnet 124 is deposited along with the photoresist 120 and the electroformed alloy. Further layers of alloy and photoresist are deposited in Figures 13d and 13e. The layer of 13f comprises the electrical coils 126. As multiple layer coils are preferred, this layer may be

repeated a number of times. More layers of photoresist and metal alloy are deposited in Figures 13g and 13h.

Finally, in Figure 13i, the photoresist is removed to form the separate armature.

Whilst all the previous bias flux actuators have been depicted using only a single coil layer it is possible to use two layers of coils as shown in Figure 14. The flux from the magnet is the same whether there is one coil or two. However, the force generated by the armature can be increased by adding a second bias field from the second coil positioned on the opposite side of the magnet to the first coil.

Whilst two coils and a single magnet are shown, multiple magnets and multiple coils can be added in further layers.

The embodiments have also been described with respect to linear channels. It equally possible to utilise other chamber architectures including, but not exclusively, architectures where the acoustic wave travels radially of the nozzle as described with regard to WO 99/01284 the contents of which are incorporated herein.

Each feature disclosed in this specification (which term includes the claims) and / or shown in the drawings may be incorporated in the invention independently of other disclosed and / or illustrated features.

CLAIMS

1. Droplet deposition apparatus comprising elongate channel walls defining an elongate liquid channel, one of said channel walls being resiliently deformable in an actuation direction orthogonal to the channel length; an ejection nozzle connected with the channel at a point intermediate its length; a liquid supply providing for continuous flow of liquid along the channel; acoustic boundaries at respective opposing ends of the channel serving to reflect acoustic waves in the liquid of the channel; and an actuator remote from the channel and the liquid supply, acting in said actuation direction upon said resiliently deformable channel wall to create acoustic waves in the liquid of the channel and thereby cause droplet ejection through said nozzle.

2. Droplet deposition apparatus according to Claim 1, wherein said resiliently deformable channel wall forms a liquid seal isolating the actuator from liquid in the channel.

3. Droplet deposition apparatus according to Claim 1 or Claim 2, wherein the nozzle opposes the resiliently deformable channel wall in the actuation direction.

4. Droplet deposition apparatus according to any one of the preceding claims, wherein said resiliently deformable channel wall comprises a substantially rigid element capable of transmitting force from the actuator to liquid in the channel and at least one flexure element.

5. Droplet deposition apparatus according to Claim 4, wherein said rigid element extends along the length of the channel.

6. Droplet deposition apparatus according to Claim 4 or Claim 5, wherein said resiliently deformable channel wall comprises a plurality of flexure elements arranged to constrain movement of the rigid element to said actuation direction.

7. Droplet deposition apparatus according to Claim 6, wherein at least one of said flexure elements contacts liquid in the channel and is stiff with respect to liquid pressure.

8. Droplet deposition apparatus according to any one of Claims 4 to 7, wherein said flexure elements are arranged in a parallelogram linkage with respect to the rigid element.

9. Droplet deposition apparatus according to any one of Claims 4 to 8, wherein the actuator comprises a push-rod acting on said rigid element.

10. Droplet deposition apparatus according to Claim 9, wherein the push-rod is carried on said rigid element.

11. Droplet deposition apparatus according to Claim 9 or Claim 10, wherein the push-rod serves as the armature in an electromagnetic actuator arrangement.

12. Droplet deposition apparatus any one of the preceding claims, wherein the actuator operates electromagnetically.

13. Droplet deposition apparatus according to Claim 11 or Claim 12, wherein the actuator comprises an armature displaced through modulation in flux distribution.

14. Droplet deposition apparatus according to any one of the preceding claims, comprising a first planar component comprising a plurality of rigid channel walls corresponding with a set of parallel channels; and a plurality of nozzles, one for each channel; and a second planar component disposed parallel with the first planar component, the second planar component comprising an actuator for each channel;

15. Droplet deposition apparatus according to Claim 14, wherein the first planar component further comprises a resiliently deformable channel wall for each channel.

16. Droplet deposition apparatus according to Claim 14 or Claim 15, wherein said first component is integral.

17. Droplet deposition apparatus according to any one of Claims 14 to Claim 16, wherein said first component is manufactured by a process comprising the step of etching away material to define the channel walls.

18. Droplet deposition apparatus according to any one of Claims 14 to Claim 17, wherein said first component is formed from silicon.

19. Droplet deposition apparatus according to any one of Claims 14 to Claim 18, wherein said second component is a laminate manufactured through the repeated formation and selective removal of layers.

20. Droplet deposition apparatus comprising an elongate liquid channel capable of sustaining acoustic waves travelling in the liquid along the length of the channel, a droplet ejection nozzle positioned for the ejection of a droplet in response to said acoustic waves and an electromagnetic actuator serving on receipt of an electrical drive signal to create an acoustic wave in the channel and thereby effect droplet ejection.

21. Droplet deposition apparatus according to Claim 20, wherein the actuator operates in an actuation direction orthogonal to the channel length.

22. Droplet deposition apparatus according to Claim 20 or Claim 21, wherein the actuator extends along substantially the length of the channel.

23. Droplet deposition apparatus according to any one of Claims 20 to 23, wherein the actuator is remote from the channel.

24. Droplet deposition apparatus according to any one of Claims 20 to 23, wherein the channel is defined by elongate channel walls, one of said channel walls being resiliently deformable in the actuation direction under the action of said actuator.

25. Droplet deposition apparatus according to Claim 24, wherein said resiliently deformable channel wall forms a liquid seal isolating the actuator from liquid in the channel.

26. Droplet deposition apparatus according to any one of Claims 20 to 25, further comprising acoustic boundary serving to reflect acoustic waves in the liquid of the channel.

27. Droplet deposition apparatus according to Claim 26, comprising acoustic boundaries at respective opposing ends of the channel.

28. Droplet deposition apparatus according to any one of Claims 20 to 27, wherein the ejection nozzle connected with the channel at a point intermediate its length.

29. Droplet deposition apparatus according to any one of Claims 20 to 28, further comprising a liquid supply providing for continuous flow of liquid along the channel.

30. Droplet deposition apparatus according to any one of Claims 20 to 29, wherein the actuator comprises an armature displaced through modulation in distribution of a magnetic flux of substantially constant amplitude.

31. Droplet deposition apparatus according to any Claims 20 to 30, comprising a first planar component comprising a plurality of rigid channel walls corresponding with a set of parallel channels; and a plurality of nozzles, one for each channel; and a second planar component disposed parallel with the first planar component, the second planar component comprising an actuator for each channel.

32. Droplet deposition apparatus according to Claim 31, wherein the first planar component further comprises a resiliently deformable channel wall for each channel.

33. Droplet deposition apparatus according to Claim 31 or Claim 32, wherein said first component is integral.

34. Droplet deposition apparatus according to any one of Claims 31 to Claim 33, wherein said first component is manufactured by a process comprising the step of etching away material to define the channel walls.

35. Droplet deposition apparatus according to any one of Claims 31 to Claim 34, wherein said first component is formed from silicon.

36. Droplet deposition apparatus according to any one of Claims 31 to Claim 35, wherein said second component is a laminate manufactured through the repeated formation and selective removal of layers.

37. Droplet deposition apparatus comprising an elongate liquid channel bounded in part by a resiliently deformable diaphragm; a liquid supply for the channel; an ejection nozzle communicating with the channel; and a push-rod which is separated from the liquid by the diaphragm, the push-rod being displaceable in an actuation direction orthogonal to the length of the channel to deform the diaphragm to displace liquid in the channel and thereby cause droplet ejection through said nozzle, wherein the push-rod is supported by at least one flexural

element at two locations spaced one from the other in the actuation direction.

38. Droplet deposition apparatus according to Claim 37, wherein the push-rod is constrained by said at least one flexural element against rotation about an axis parallel to the length of the channel.

39. Droplet deposition apparatus according to Claim 37 or Claim 38, wherein the push-rod is supported by at least one flexural element at each said location, the flexural elements serving as a parallelogram linkage.

40. Droplet deposition apparatus according to any one of Claims 37 to 39, wherein the diaphragm serves as one said flexural element.

41. Droplet deposition apparatus according to any one of Claims 37 to 40, wherein the push-rod is integral with the diaphragm.

42. Droplet deposition apparatus according to any one of Claims 37 to 41, wherein the nozzle opposes the diaphragm in the actuation direction.

43. Droplet deposition apparatus according to any one of Claims 37 to 42, wherein the diaphragm extends along the length of the channel.

44. Droplet deposition apparatus according to any one of Claims 37 to 43, wherein at least one of said flexure elements contacts liquid in the channel and is stiff with respect to liquid pressure.

45. Droplet deposition apparatus according to any one of Claims 37 to 44, wherein the push-rod communicates at end remote from the diaphragm with an actuator.

46. Droplet deposition apparatus according to Claim 45, wherein the actuator comprises an electromagnet actuator.

47. Droplet deposition apparatus according to any one of Claims 37 to 46, wherein the push-rod serves as the armature in an electromagnetic actuator.

48. Droplet deposition apparatus according to Claim 46 or Claim 47, wherein the actuator comprises an armature displaced through modulation in flux distribution.

49. Droplet deposition apparatus according to any one of Claims 37 to 48, further comprising acoustic boundaries at respective opposing ends of the channel serving to reflect acoustic waves in the liquid of the channel; deformation of the diaphragm by the push-rod serving to create acoustic waves in the liquid of the channel and thereby cause droplet ejection through said nozzle.

50. A method of manufacturing droplet deposition apparatus, comprising the steps of forming a first planar component comprising a plurality of rigid channel walls corresponding with a set of parallel channels and a resiliently deformable channel wall for each channel, said resiliently deformable channel walls lying in a common plane; and forming a second planar component comprising a linear actuator for each channel, said actuators having respective actuation directions which are parallel; the first and second planar components lying in a parallel relationship in the manufactured apparatus, with said actuation direction disposed orthogonal to said common plane and the actuators serving to actuate the respective channels through deformation of the associated resiliently deformable channel walls.

51. A method according to Claim 50, wherein the step of forming the first planar component comprises the step of forming a planar wafer and etching away material from one planar face of the wafer to define the channel walls.

52. A method according to Claim 51, wherein the step of forming the first planar component further comprises the step of etching away material from the other planar face of the wafer to define the resiliently deformable channel walls.

53. A method according to Claim 52, wherein the step of forming the first planar component comprises the step of depositing material after etching away material from said one planar face, the step of etching away material from the other planar face of the wafer serves define a layer of said deposited material as a resiliently deformable channel wall.

54. A method according to Claim 52 or Claim 53, wherein step of etching away material from the other planar face of the wafer to define the resiliently deformable channel walls serves to leave for each channel a push-rod connected with the associated resiliently deformable channel wall.

55. A method according to Claim 54, wherein each pushrod extends along substantially the length of the associated channel.

56. A method according to Claim 54 or Claim 55, wherein the step of forming the first planar component comprises the further step of forming an interaction layer bonded to the respective free ends of the pushrods.

57. A method according to any one of Claims 50 to 56, wherein said wafer is formed from silicon.

58. A method according to any one of Claims 51 to 57, wherein etching step comprises deep reactive ion etching.

59. A method according to Claim 53, wherein said wafer is formed from silicon and said deposited material comprises SiO_2 or SiN.

60. A method according to any one of Claims 50 to 59, wherein said second component is through the repeated formation and selective removal of layers.

61. A method of manufacturing droplet deposition apparatus, comprising the steps of forming a first planar component comprising a plurality of rigid channel walls corresponding with a set of parallel channels ; and forming a second planar component comprising a linear actuator for each channel, said actuators having respective actuation directions which are parallel and a resiliently deformable wall for each actuator, said resiliently deformable walls lying in a common plane ; the first and second planar components lying in a parallel relationship in the manufactured apparatus, with said actuation direction disposed orthogonal to said common plane and the actuators serving to actuate the respective channels through deformation of the associated resiliently deformable walls.

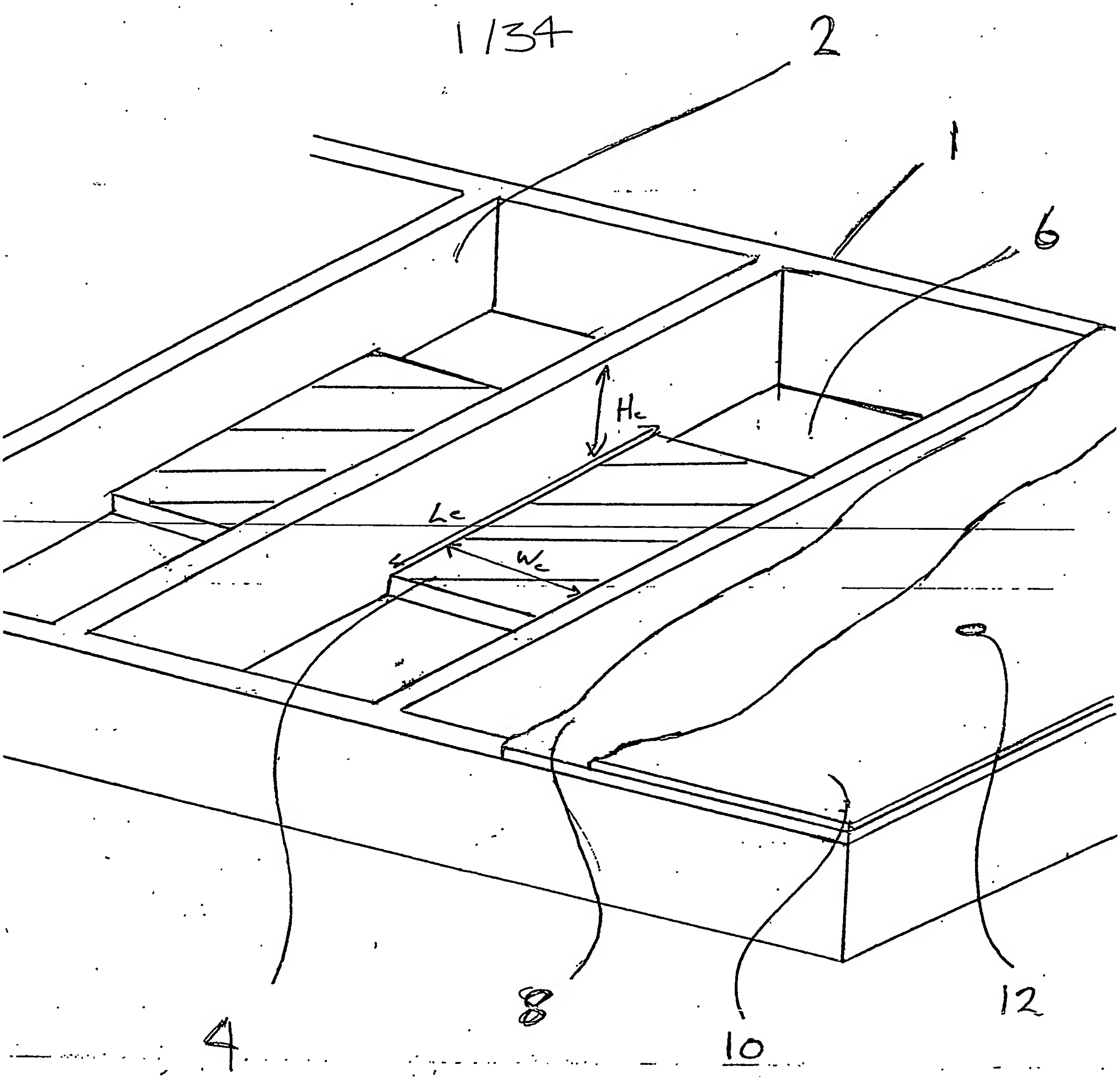


Figure 1

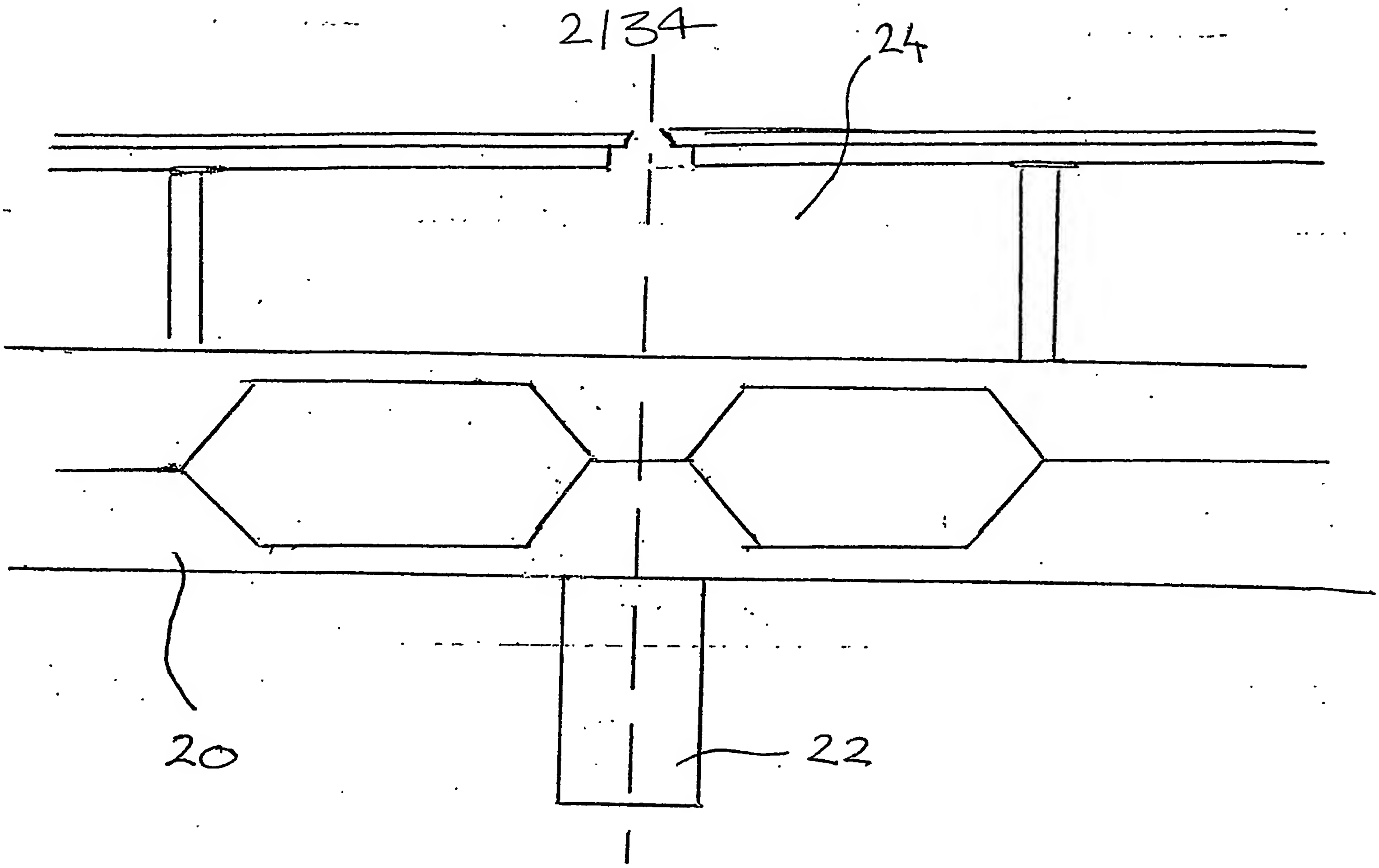


Figure 2

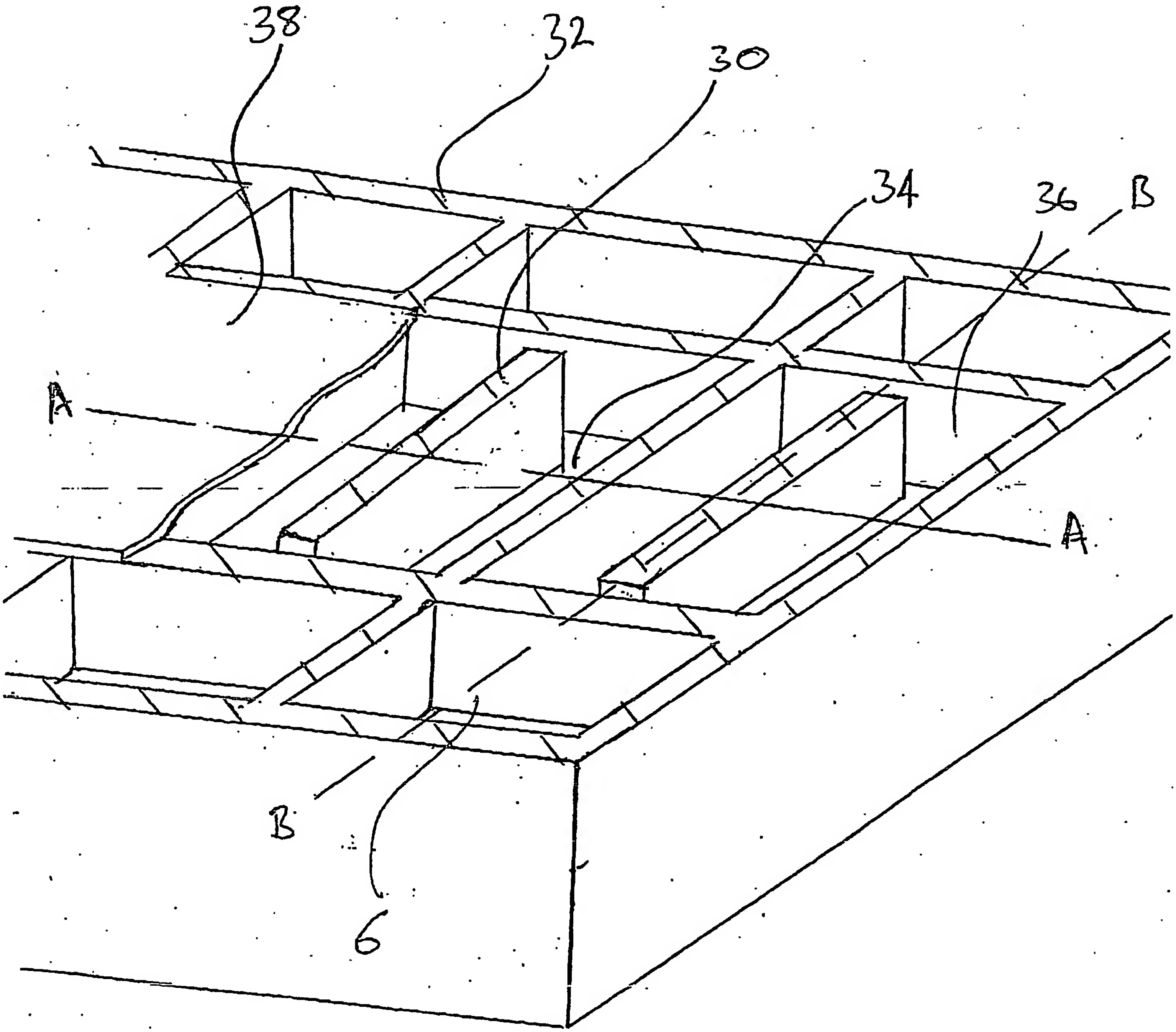


Figure 3a

4134

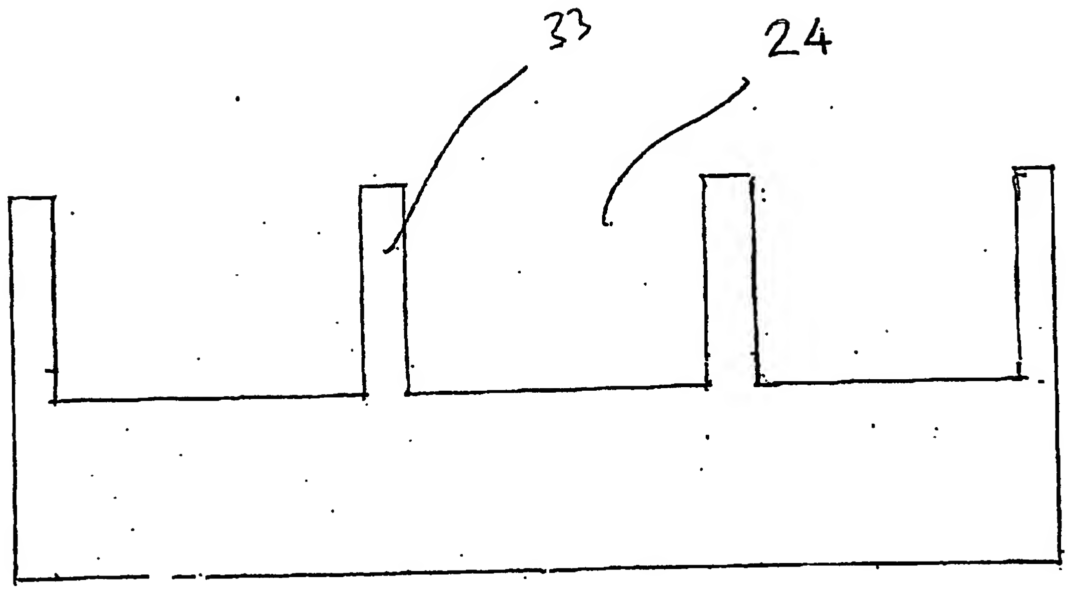


Figure 3b

5134

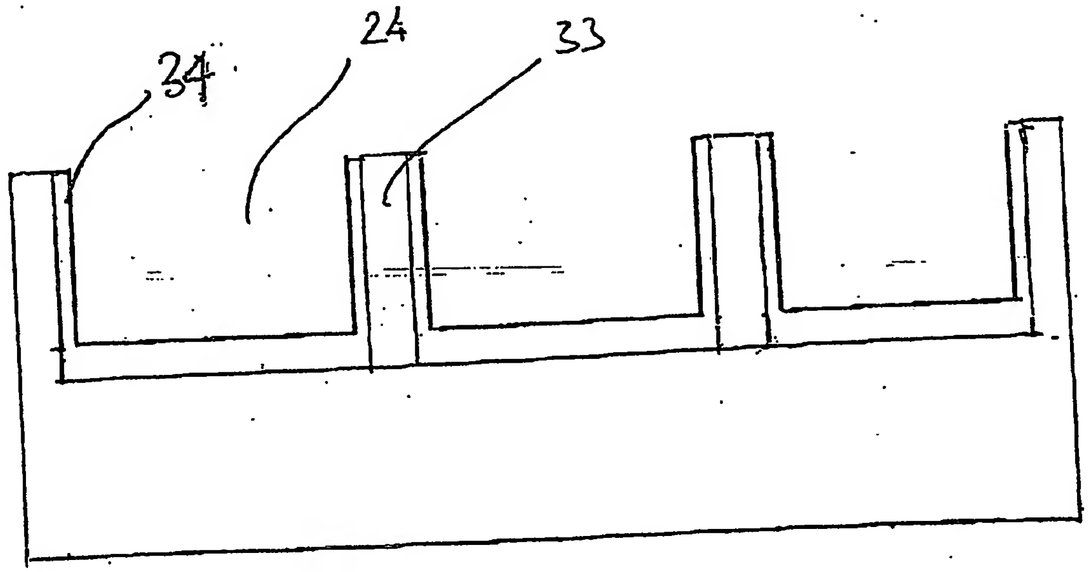


Figure 3c

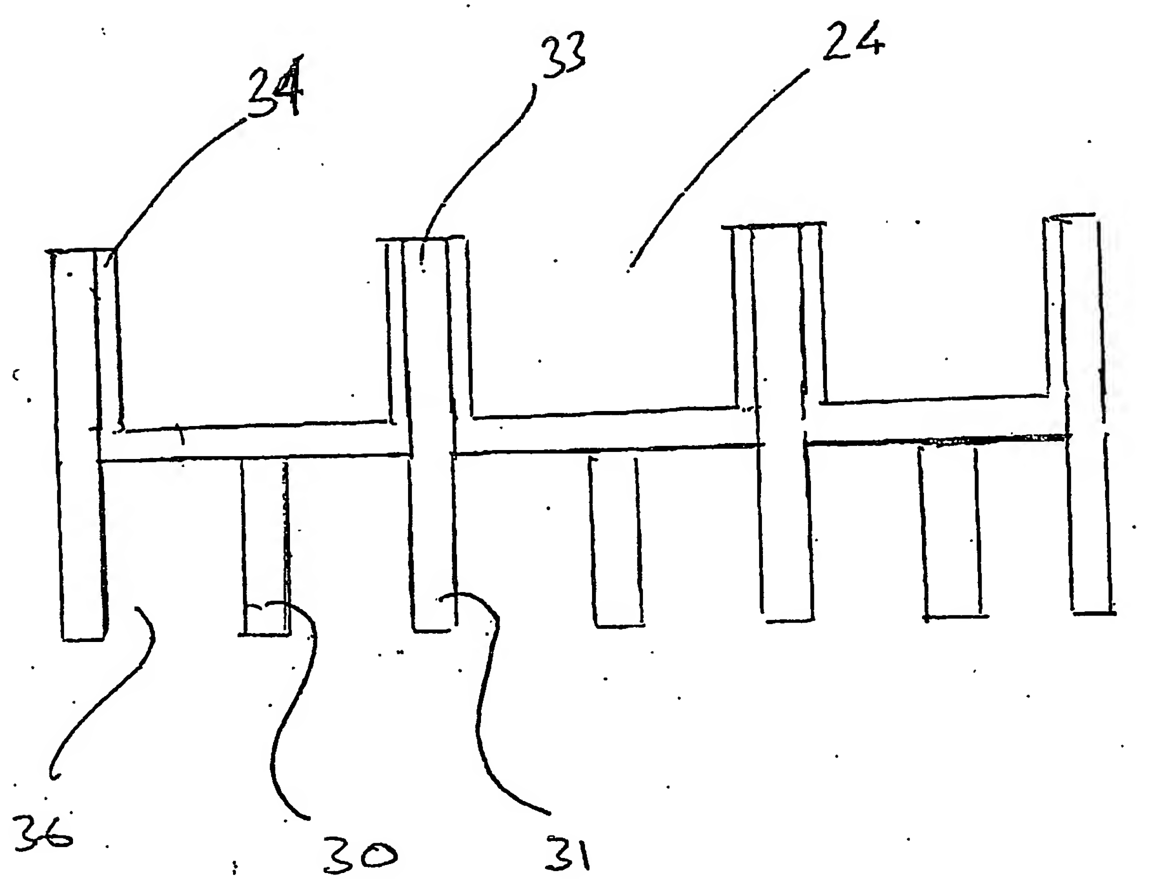


Figure 3d

7134

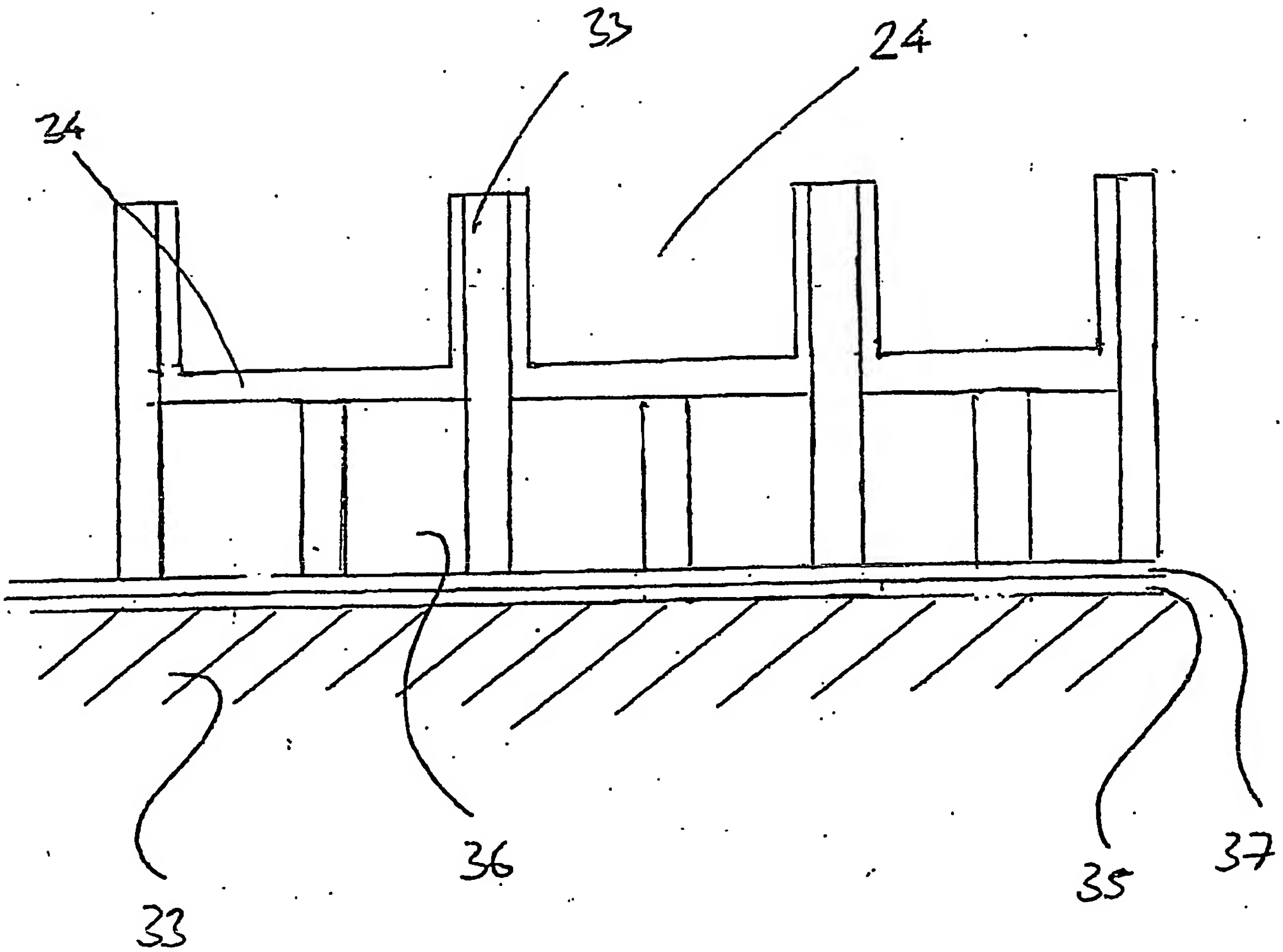


Figure 3e

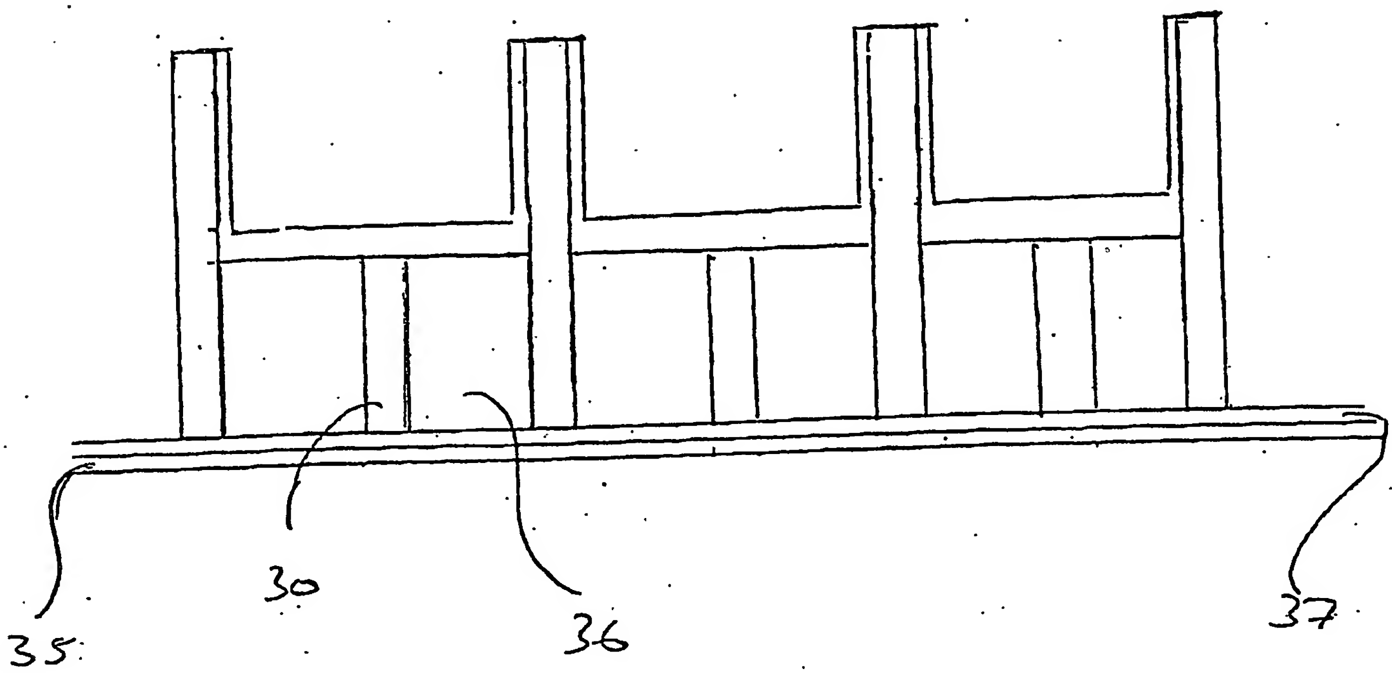


Figure 3f.

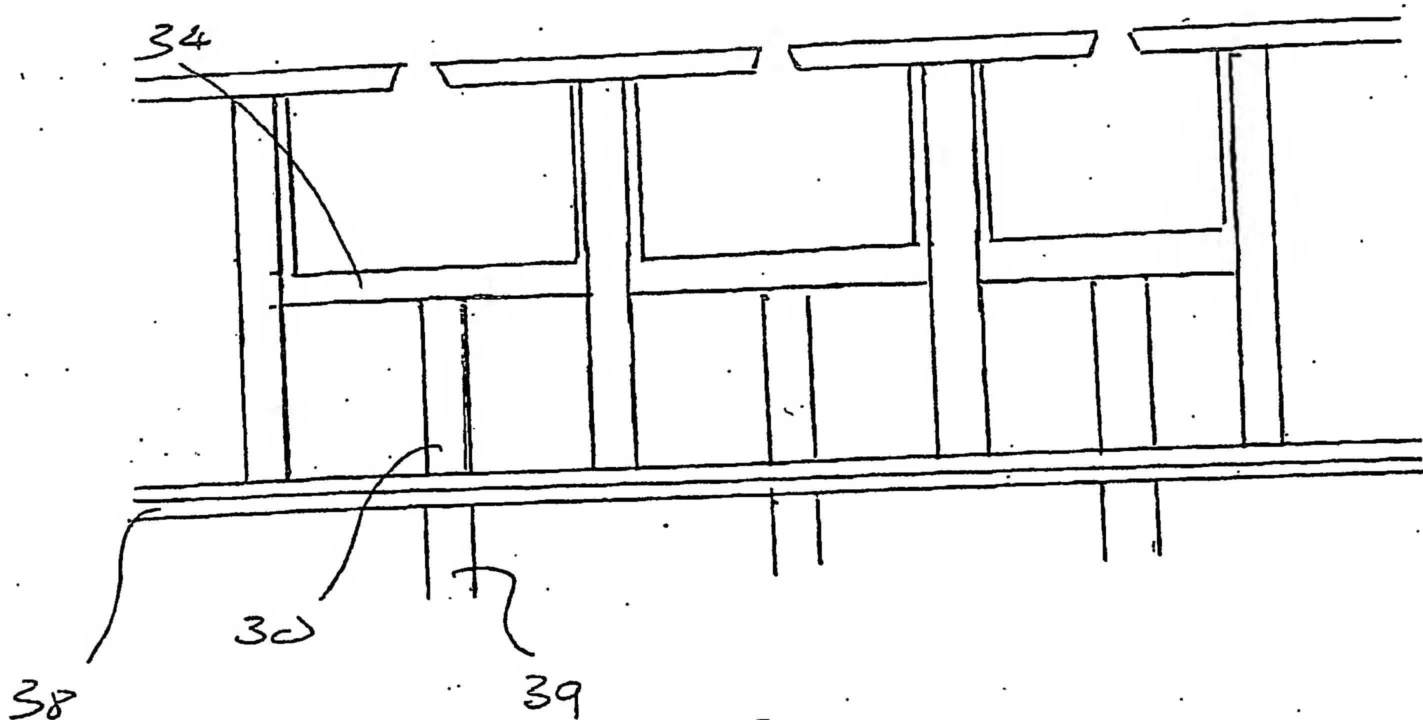


Figure 3g

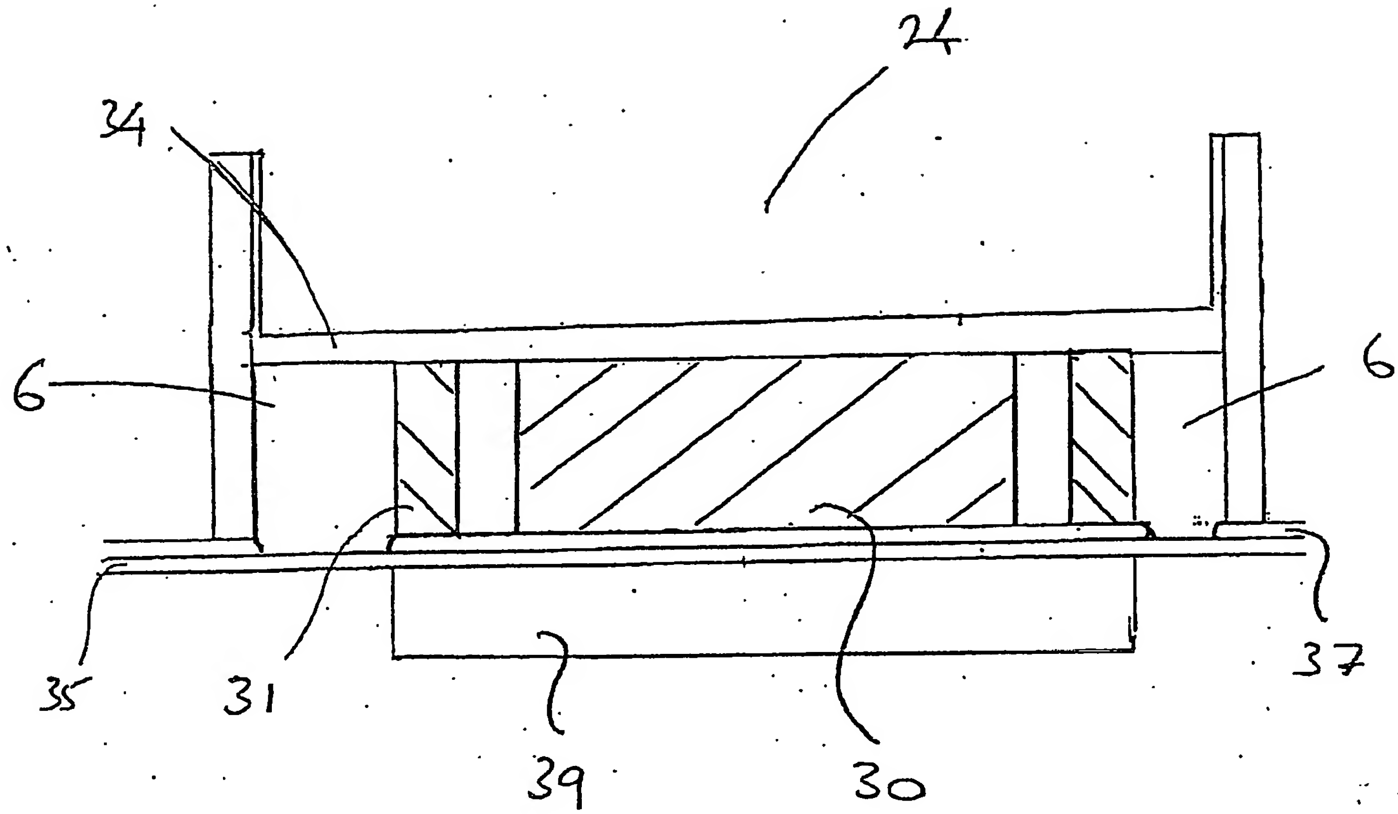


Figure 3h

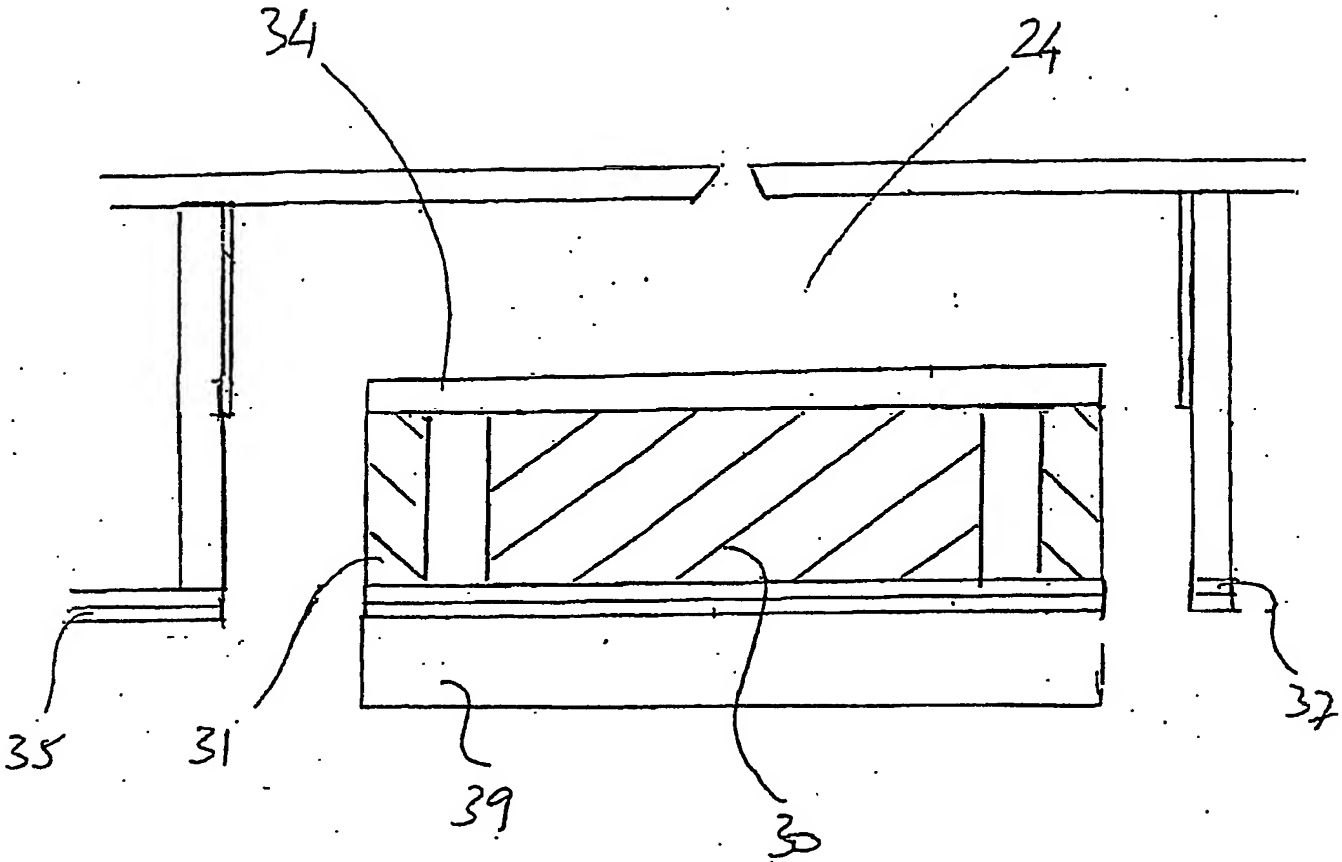


Figure 31

12134

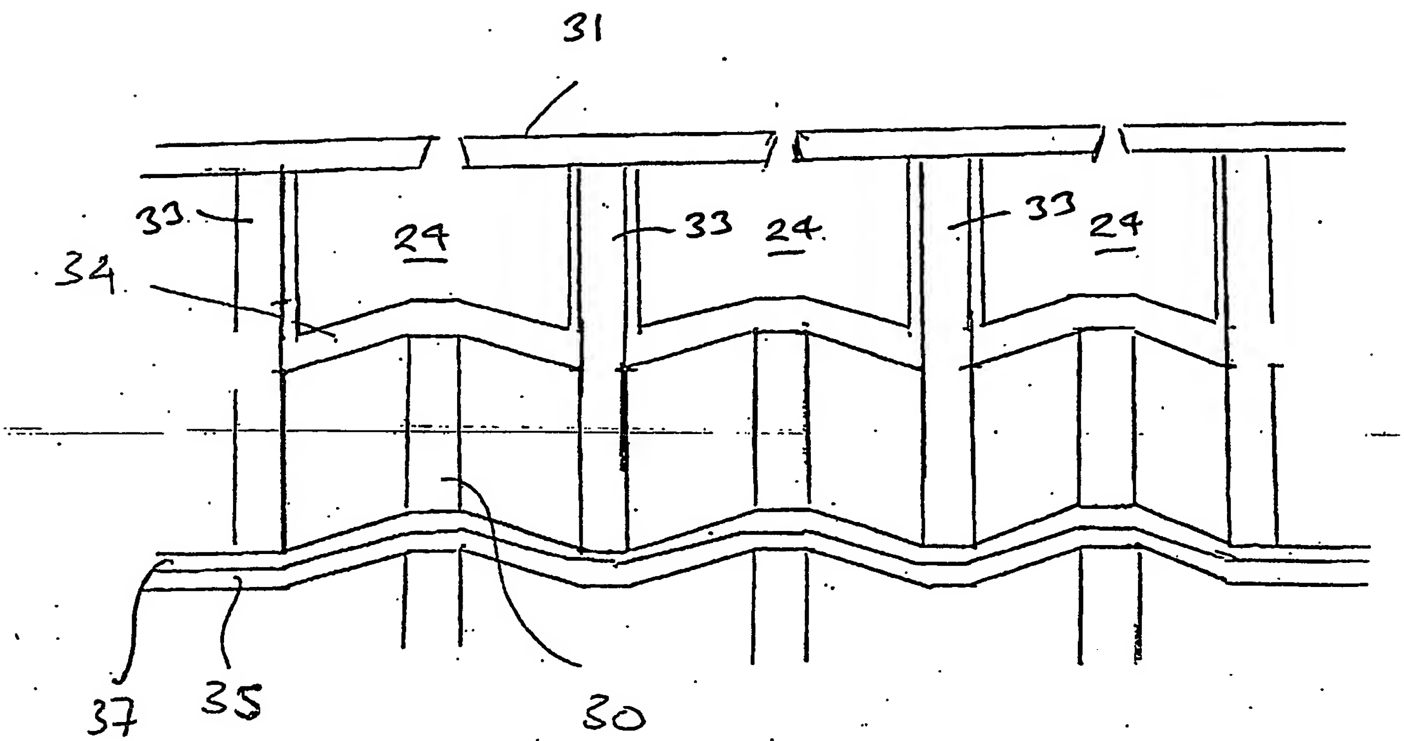


Figure 3J

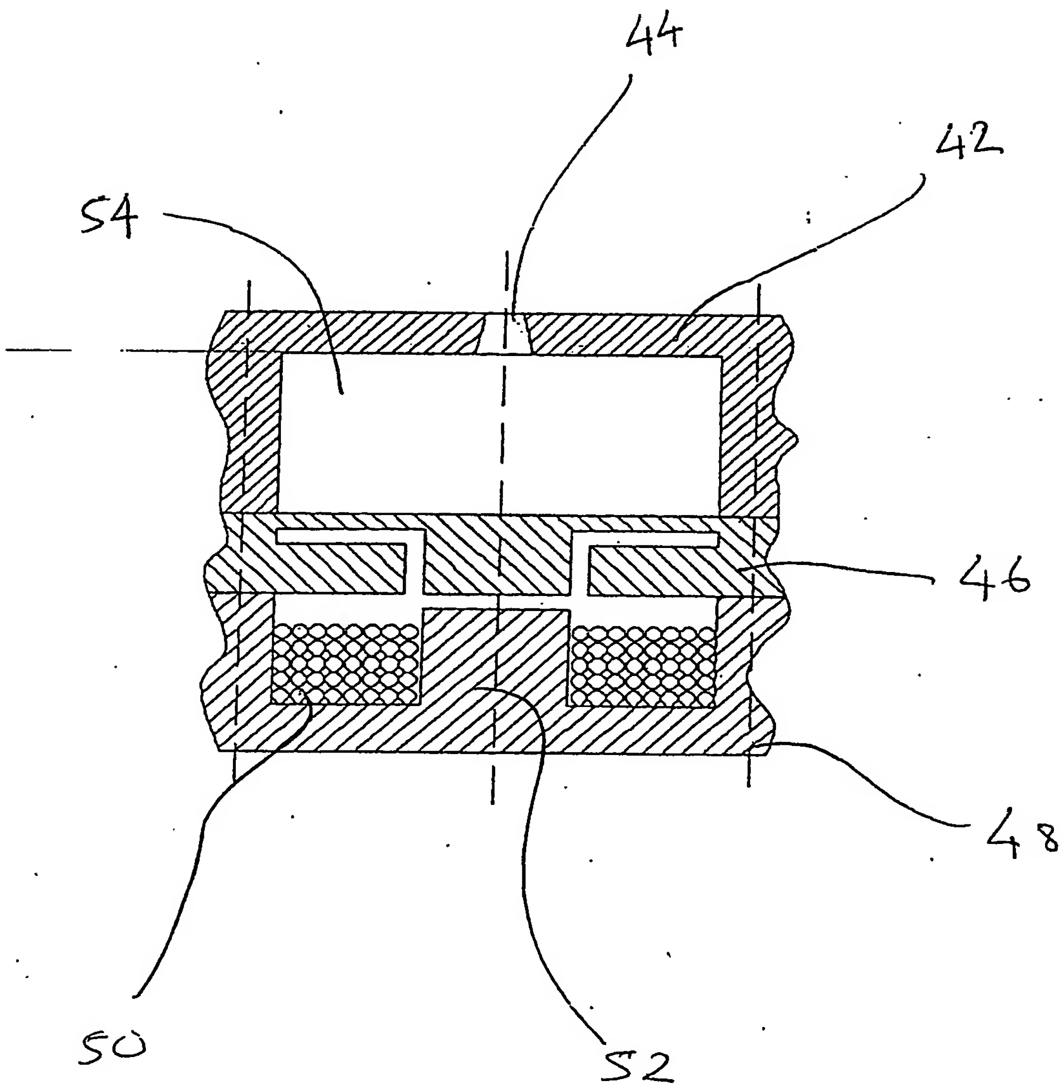


Figure 4

14134

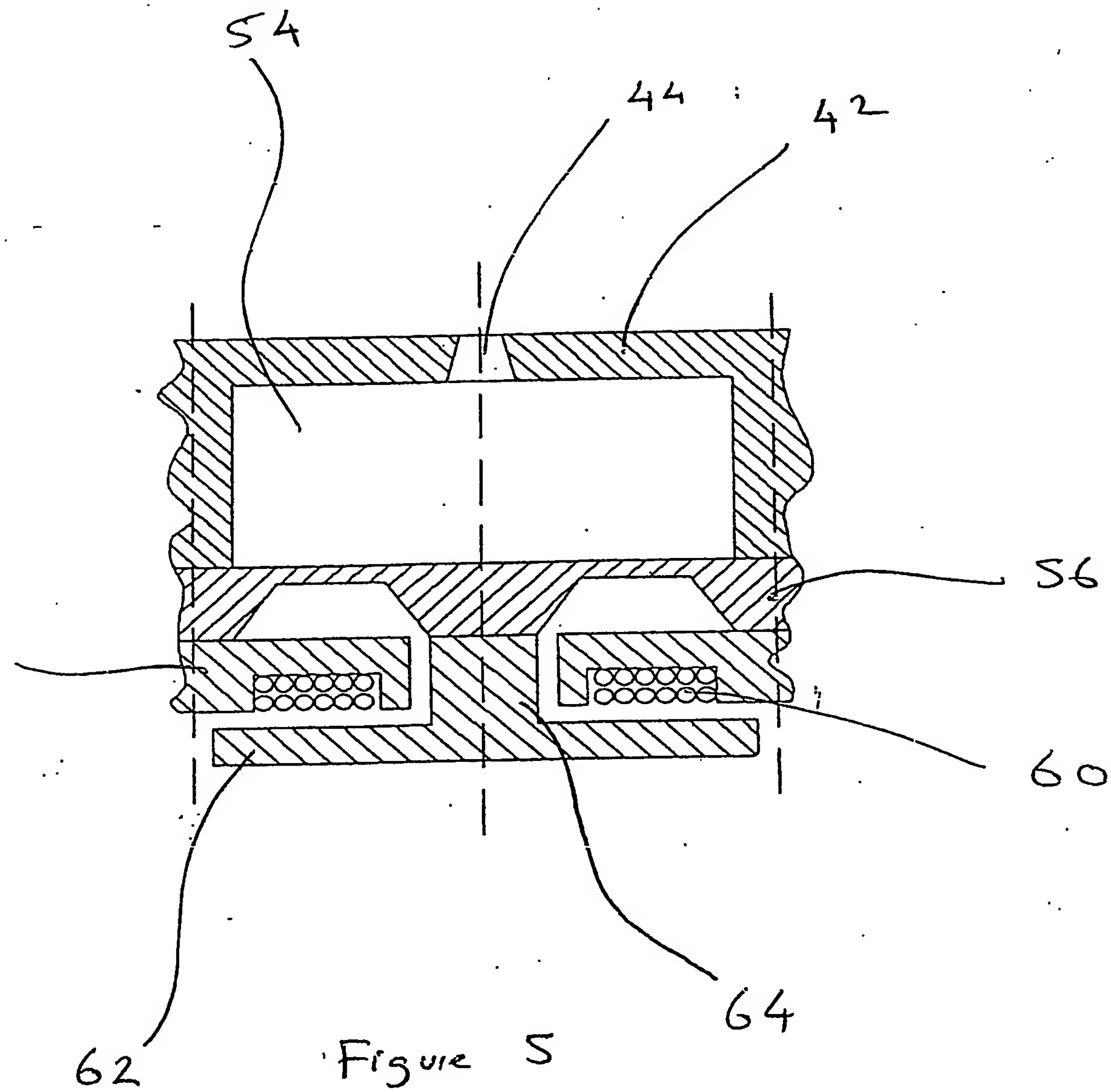


Figure 5

15134

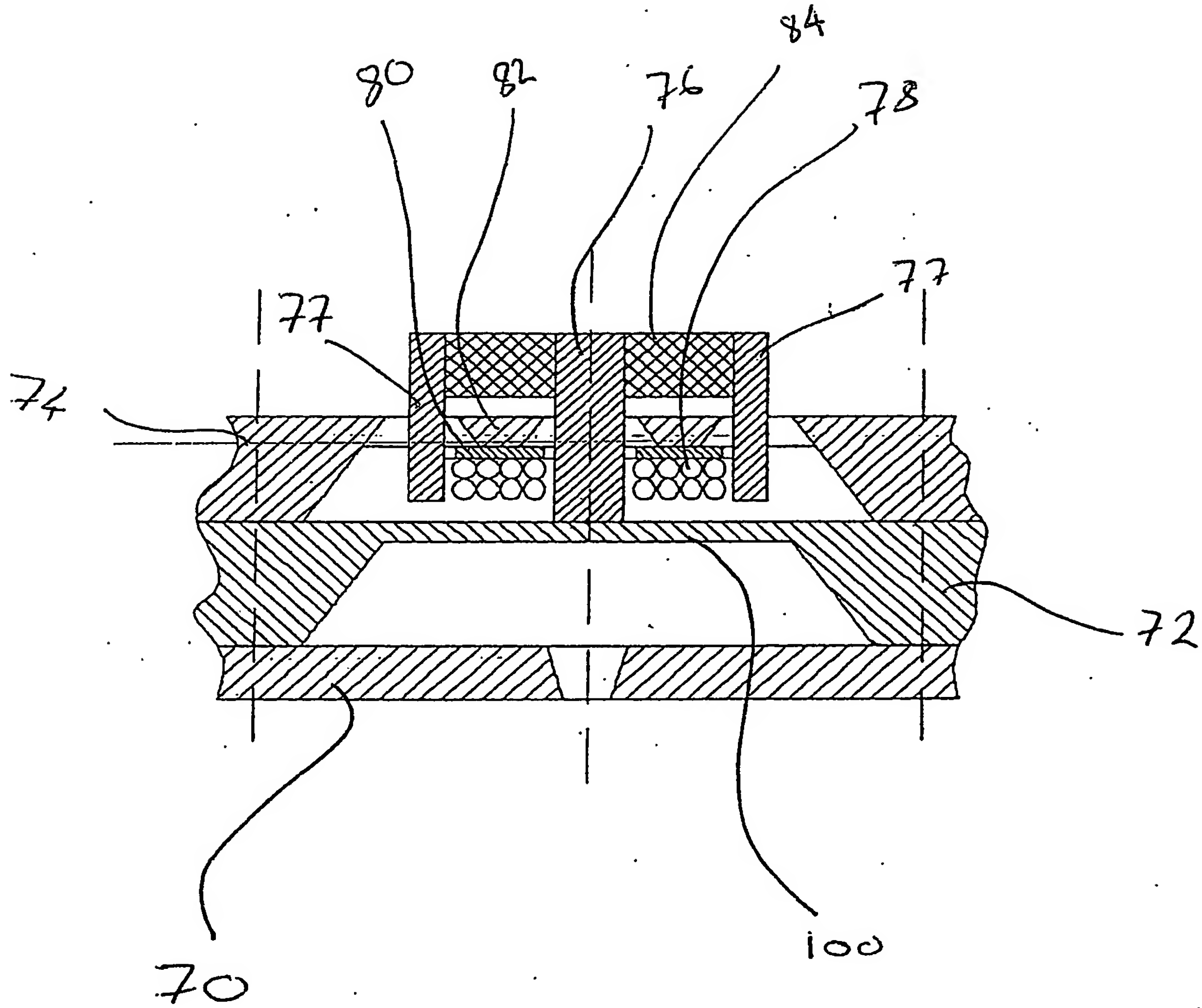


Figure 6

16134

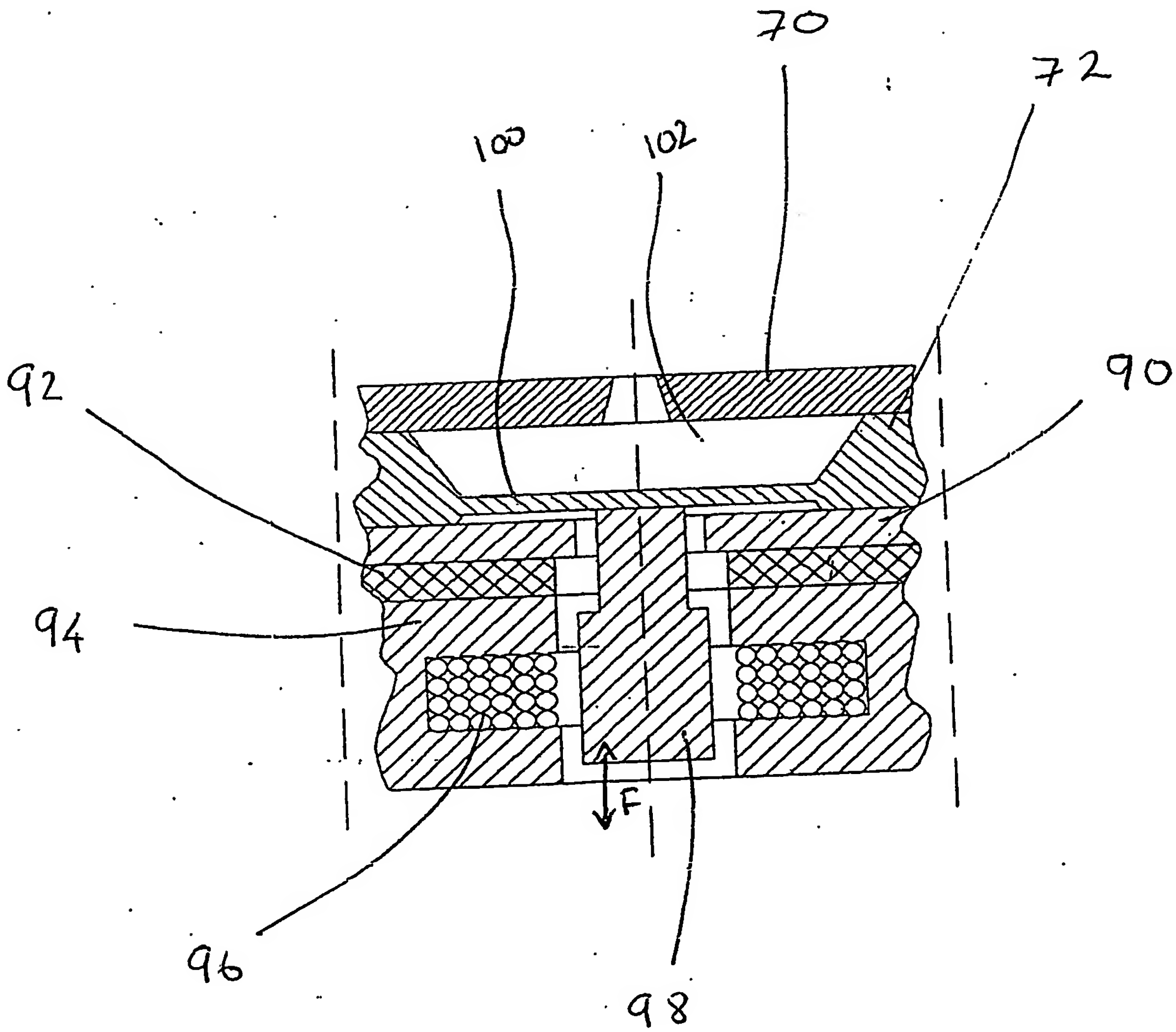


Figure 7

17134

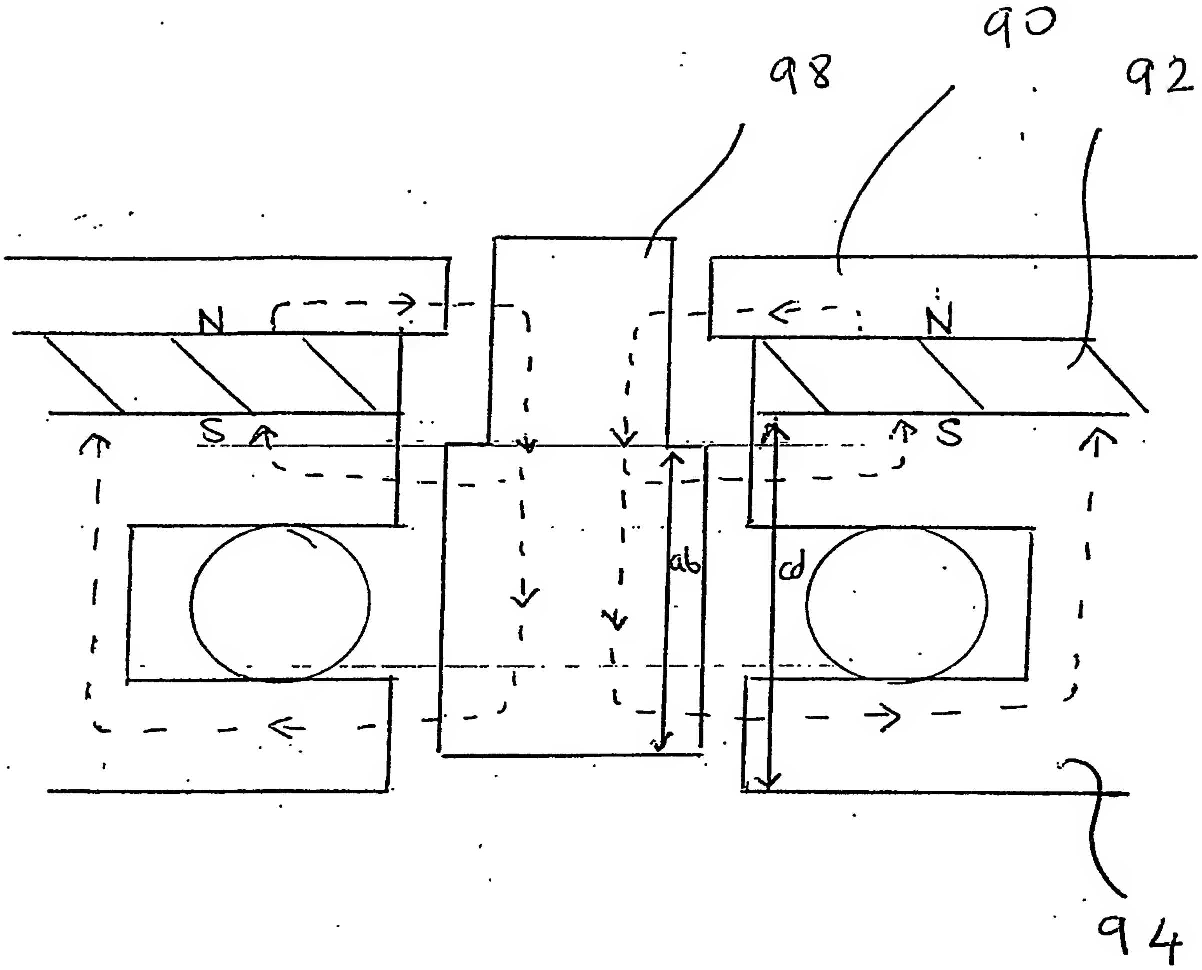


Figure 8a

18134

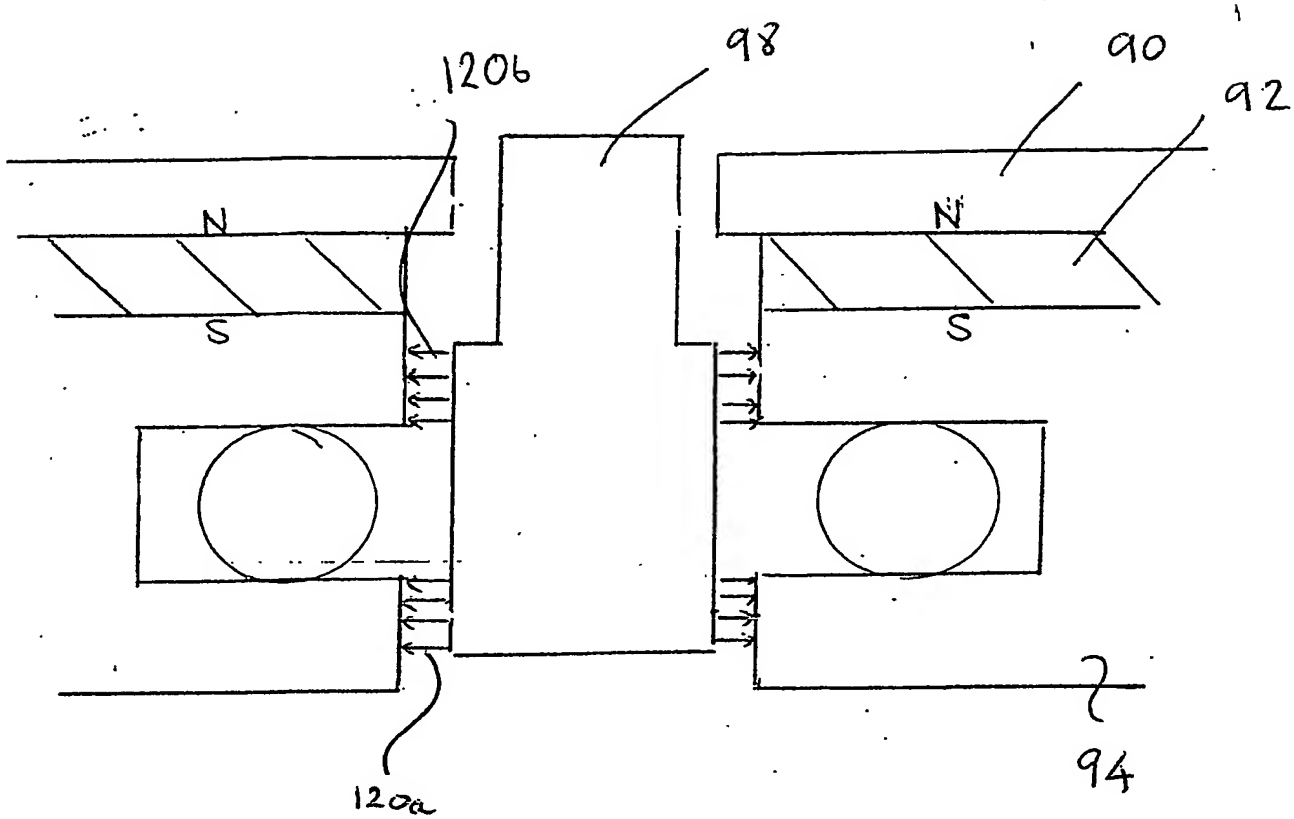


Figure 8b

19/34

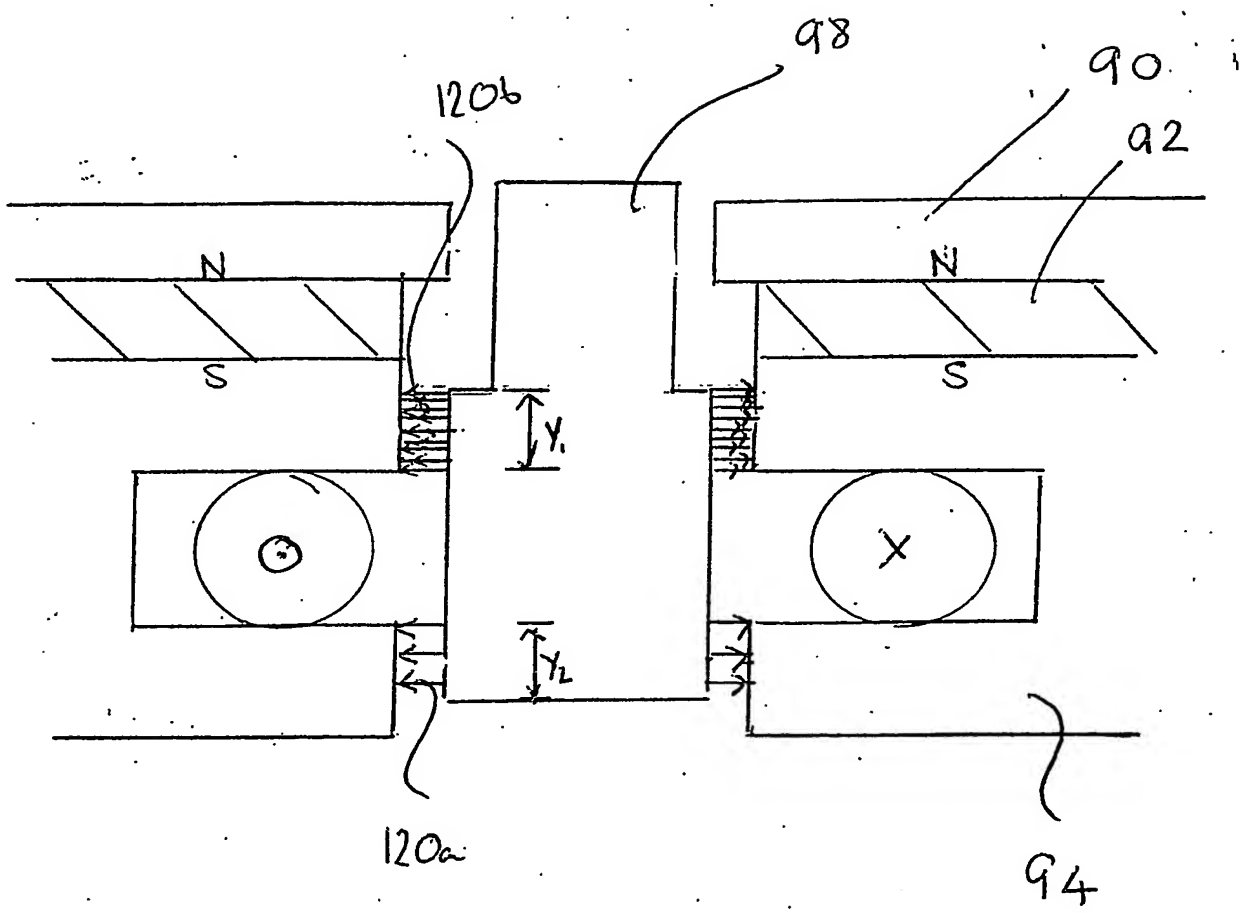


Figure 8c

20134

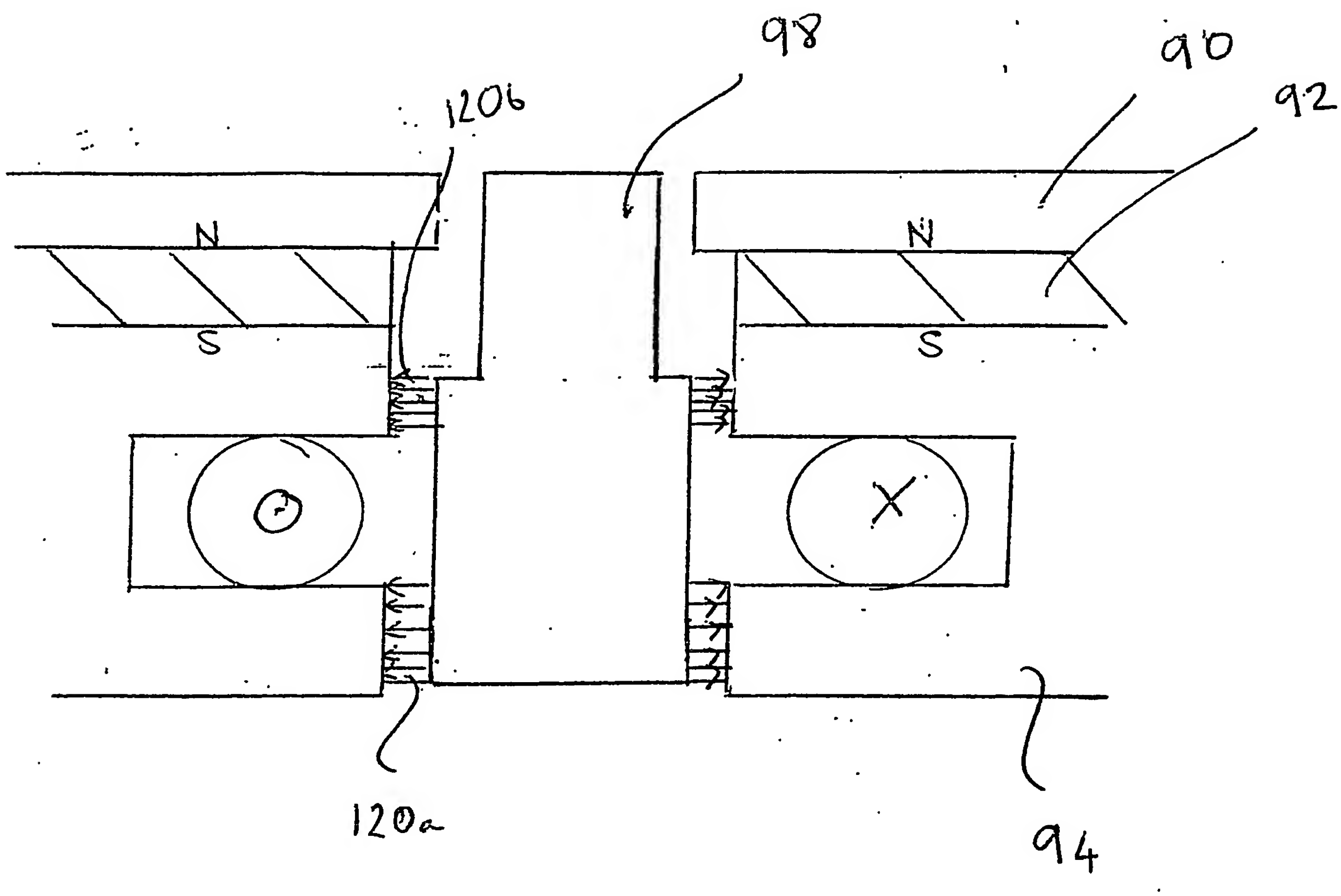
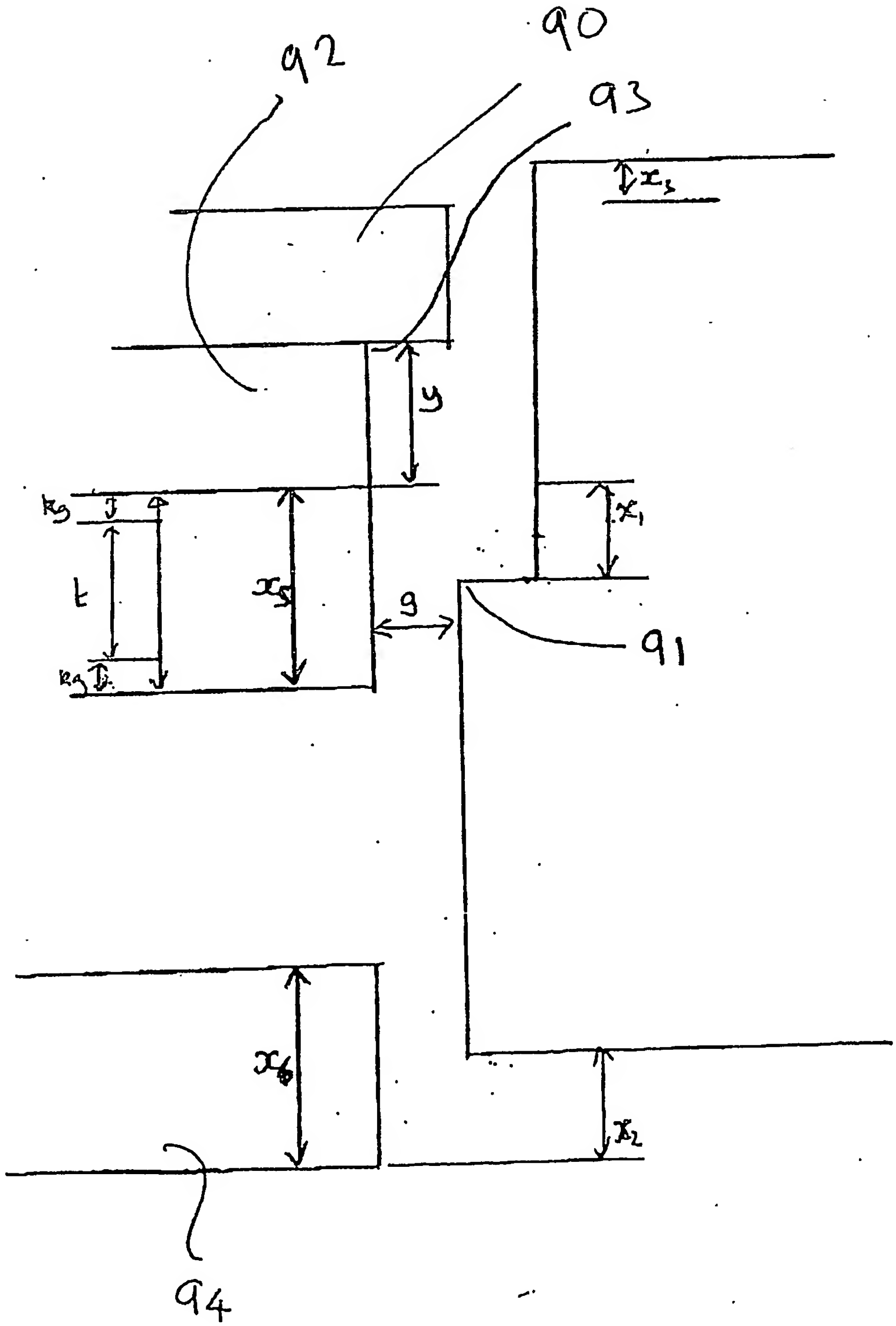


Figure 8d

Figure 9



22134

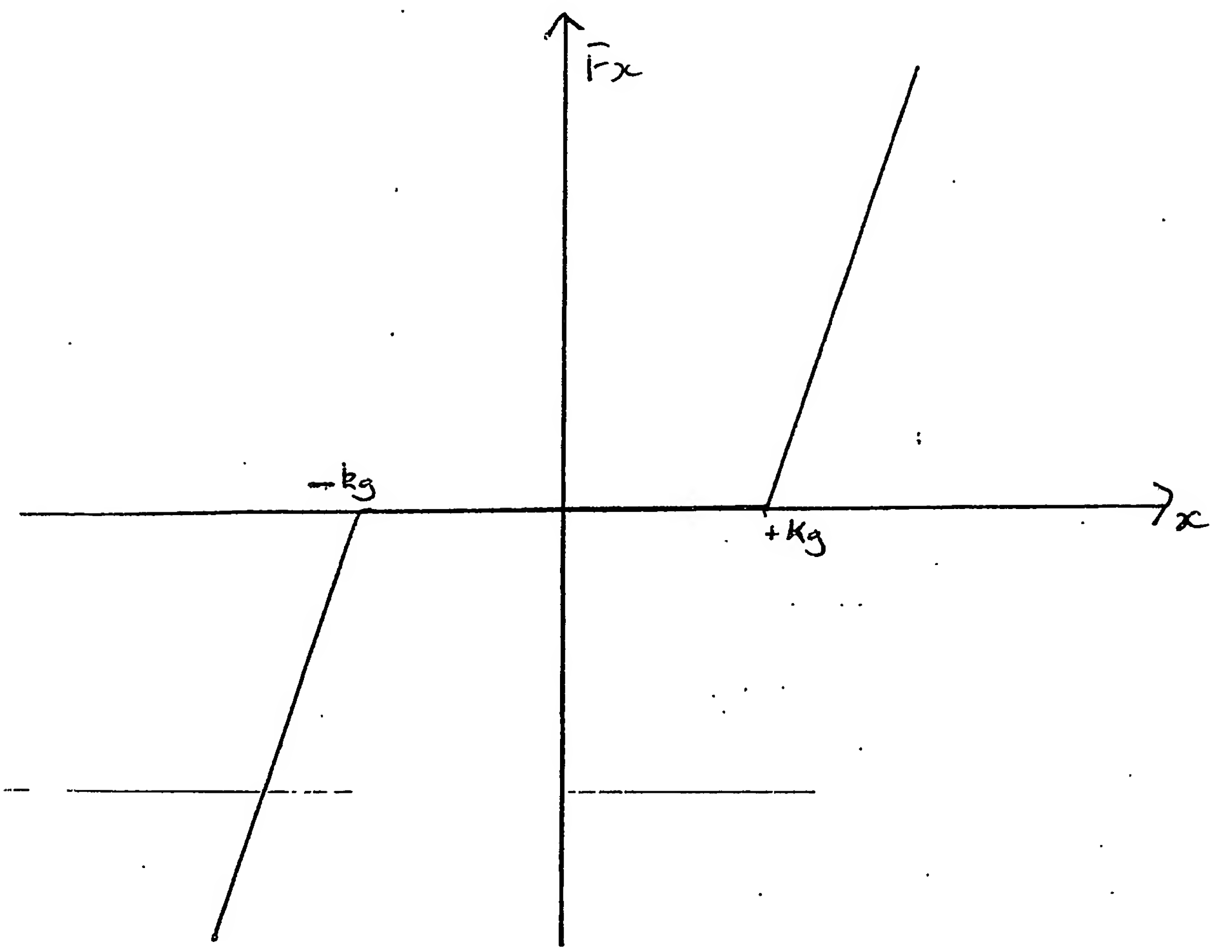


Figure 10

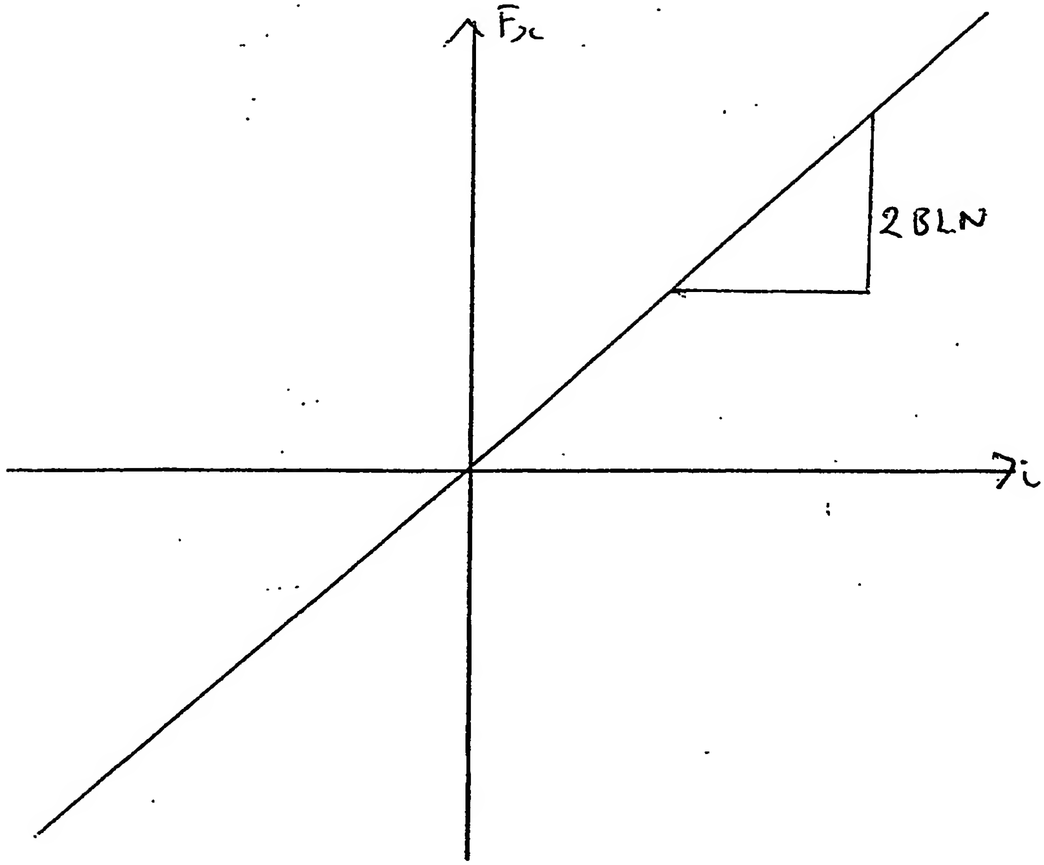


Figure 11

24134

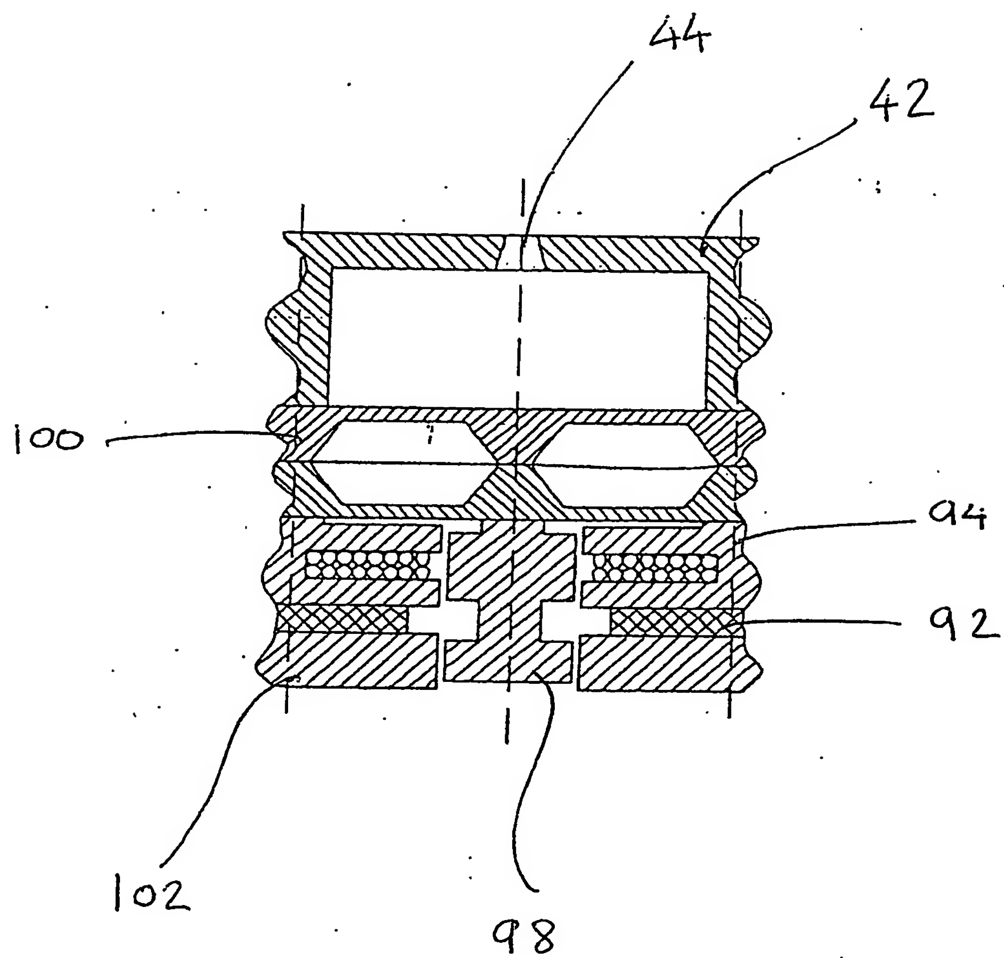


Figure 12

25134

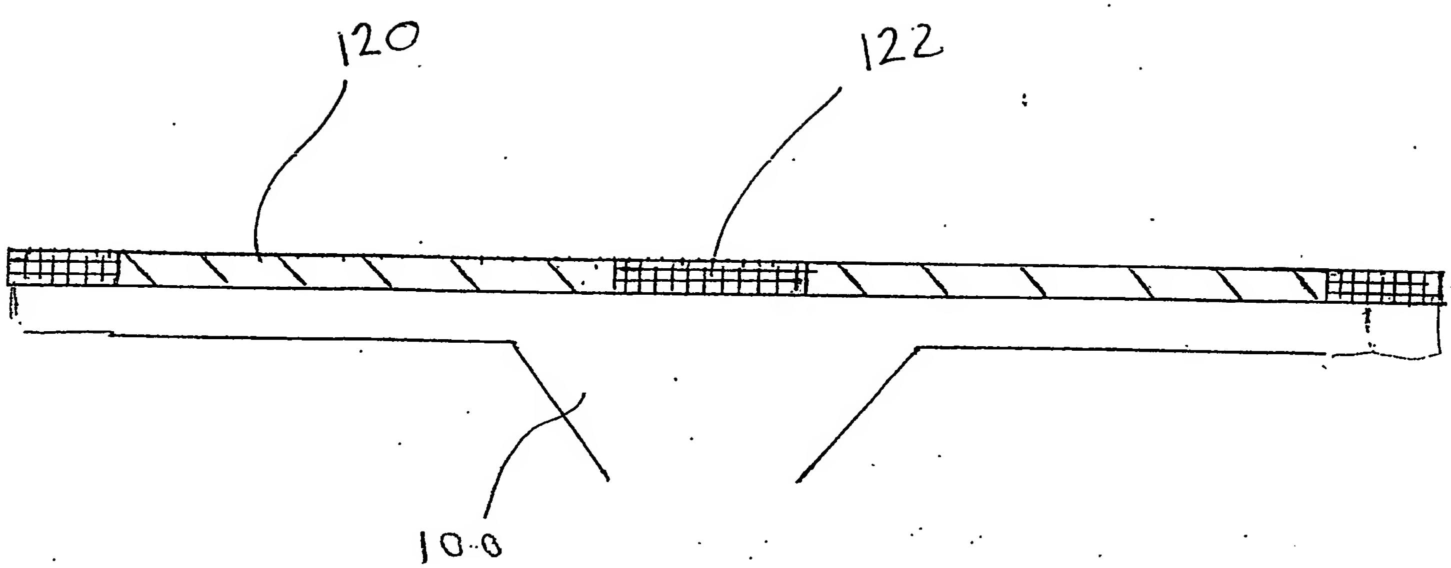


Figure 13a

26134

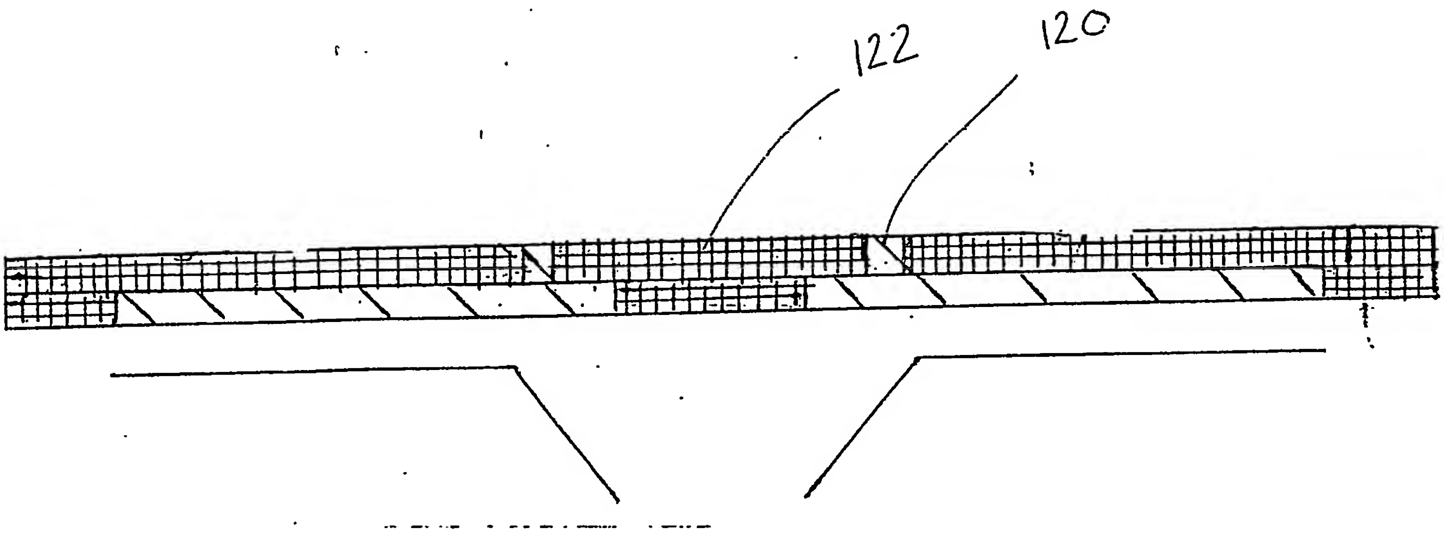


Figure 13 b.

27134

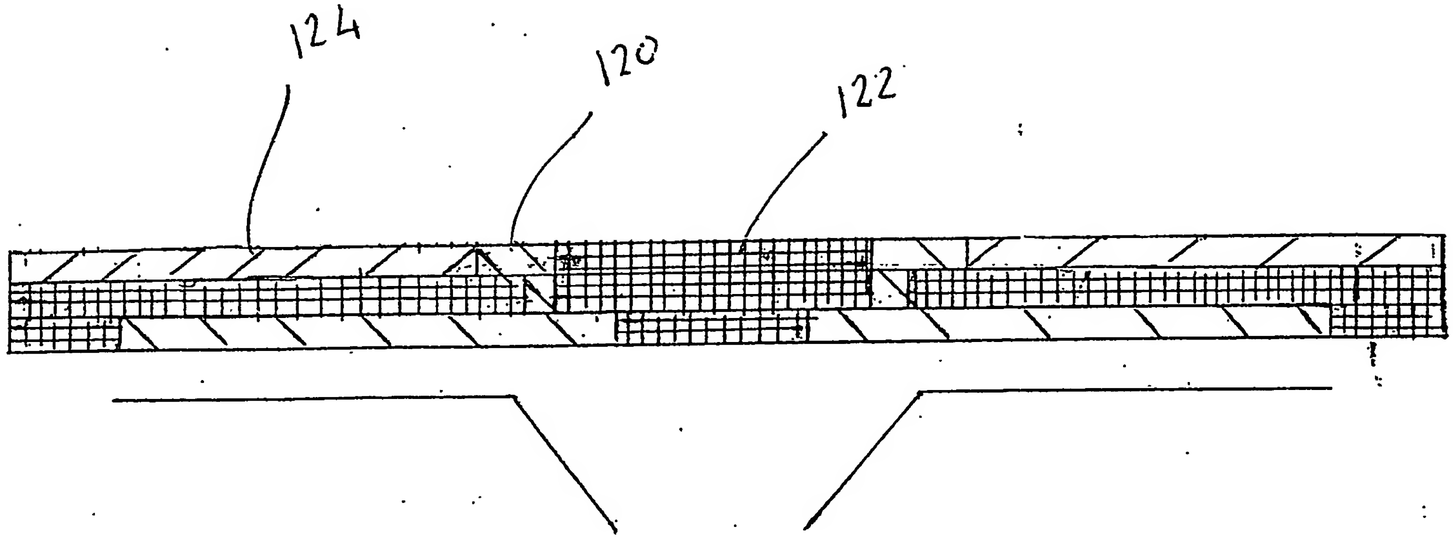


Figure 13c

28134

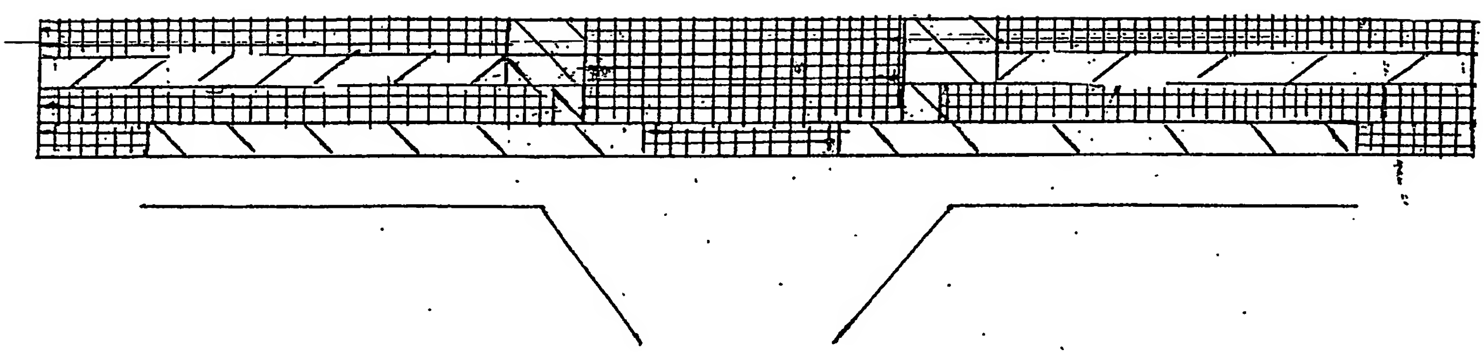
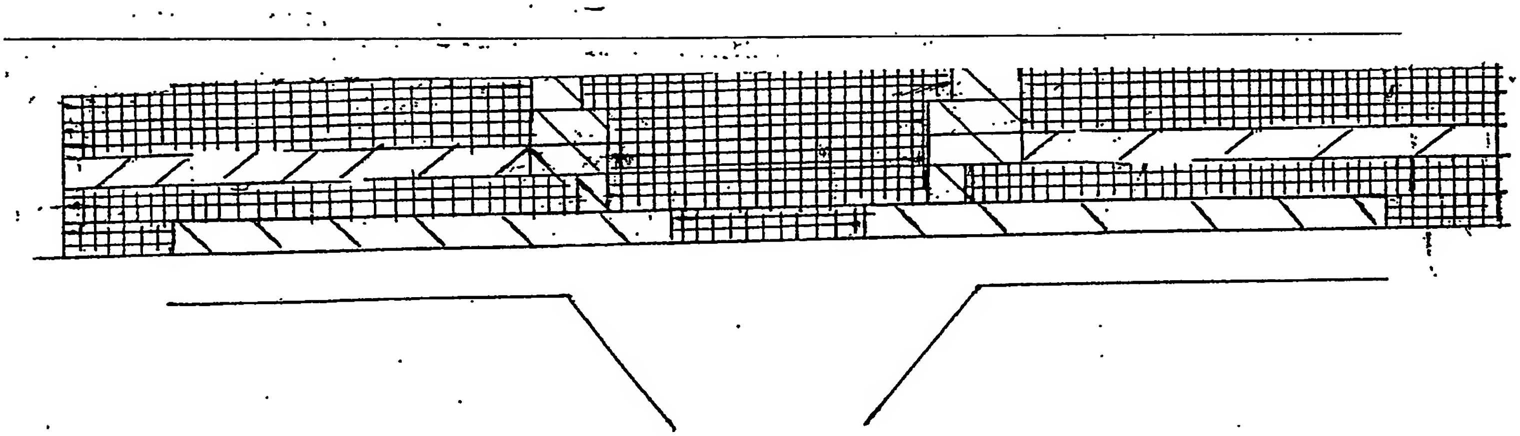


Figure 13d



Figue 13e

30134

126

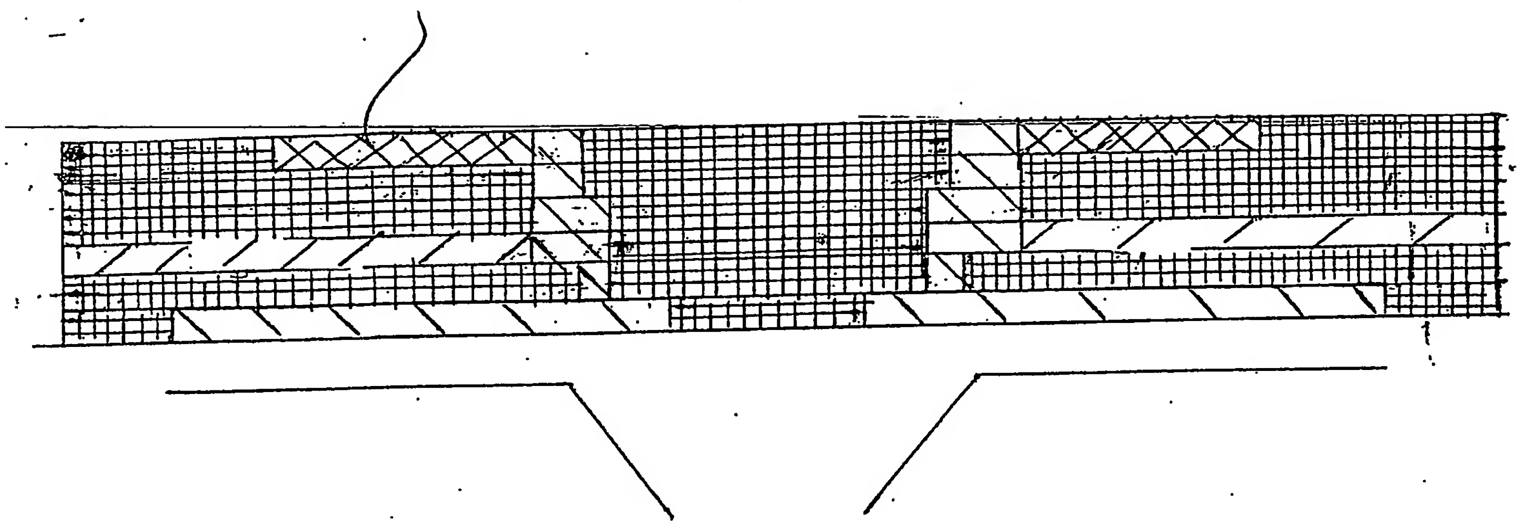


Figure 13f

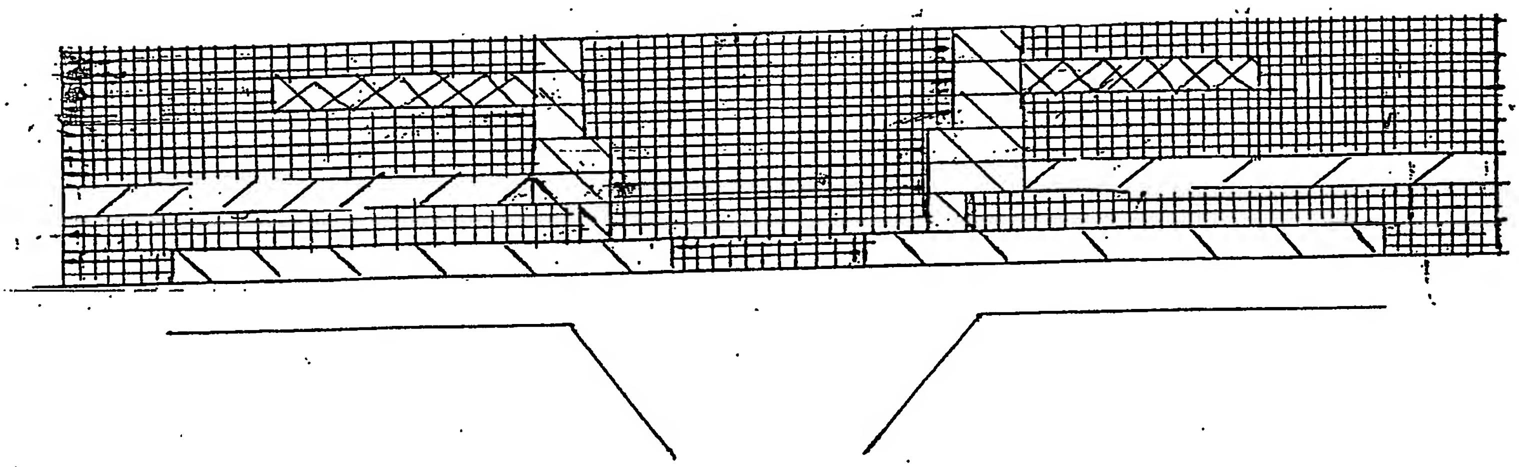


Figure 13g

32134

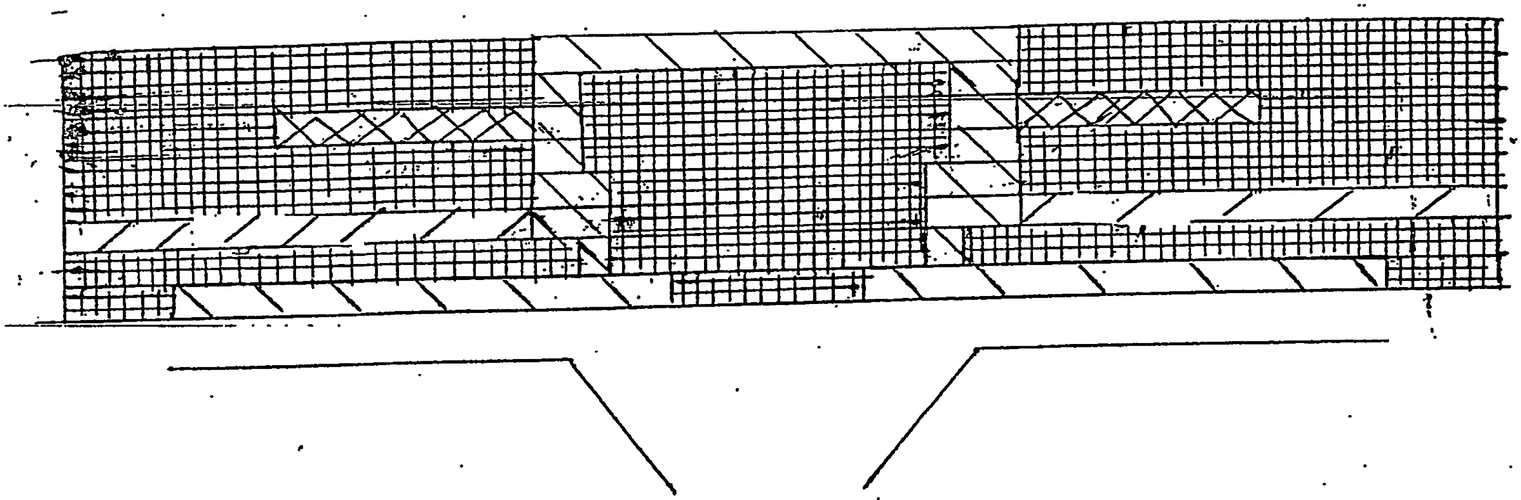


Figure 13h

33134

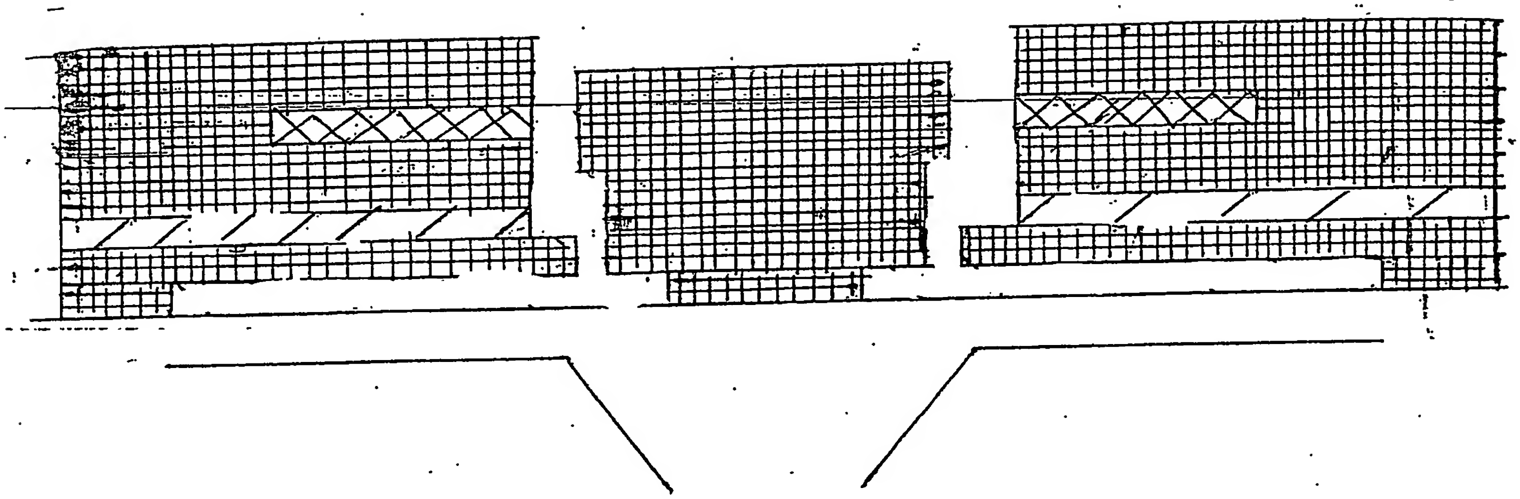


Figure 13i

34134

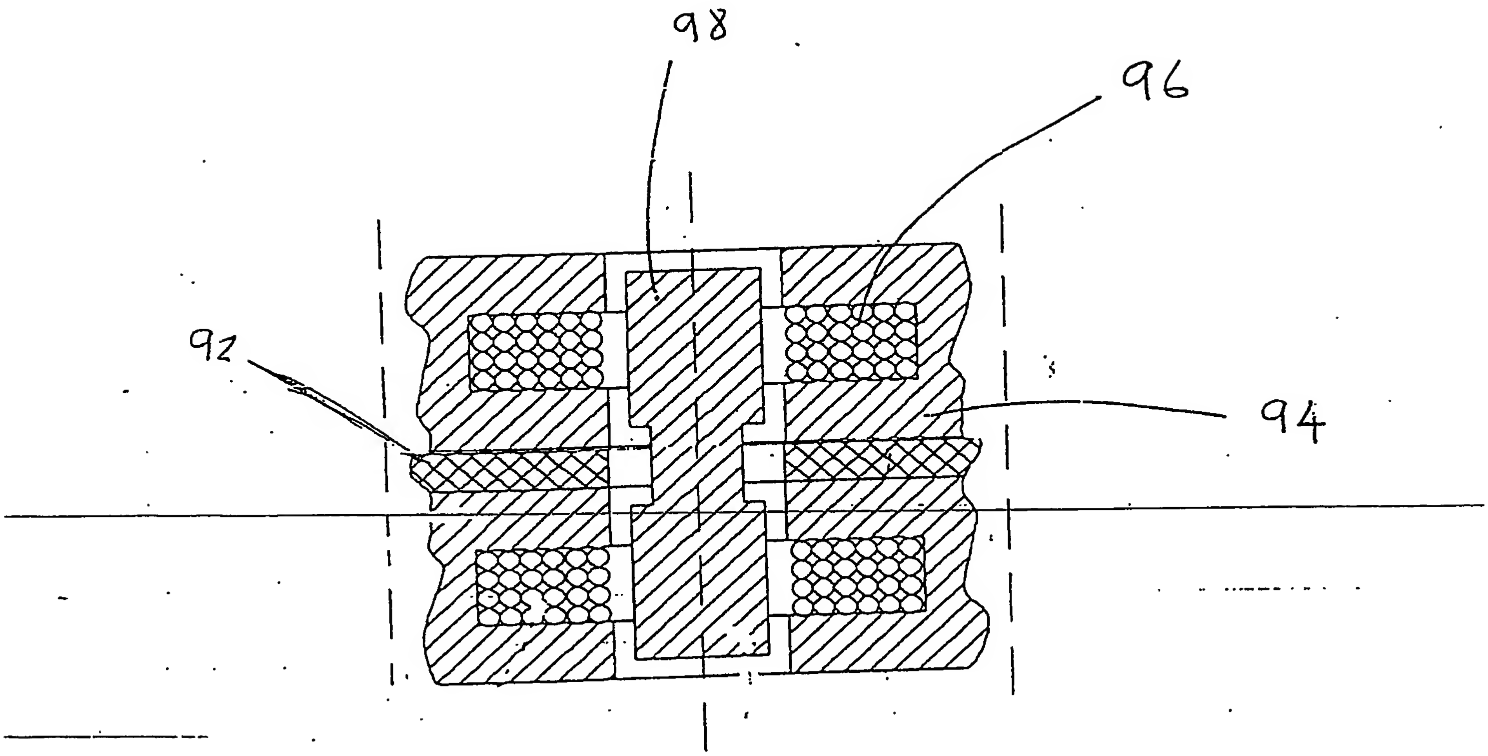


Figure 14